University of Alberta

Soil Productivity of White Spruce - Aspen Mixedwood Ecosites along Toposequences in West-Central Alberta

By

Todd Ian Little ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Masters of Science

In

Soil Science

Department of Renewable Resources

Edmonton, Alberta

Spring 2001

National Library of Canada
Bibliothèque nationale du Canada

Acquisitions and Bibliographic Services
Acquisitions et services bibliographiques

395 Wellington Street
Ottawa ON K1A 0N4
Canada

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-60457-8

Canada

University of Alberta

Library Release Form

Name of Author: **Todd Ian Little**

Title of Thesis: **Soil Productivity of White Spruce - Aspen Mixedwood Ecosites along Toposequences in west-central Alberta**

Degree: **Masters of Science**

Year this Degree Granted: **2001**

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as herein before provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

Todd Ian Little
546 Huntington Hill NW
Edmonton Alberta, T6H 5W6

17 April 2001

17 April 2001

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Soil Productivity of White Spruce - Aspen Mixedwood Ecosites along Toposequences in west-central Alberta** submitted by **Todd Ian Little** in partial fulfillment of the requirements for the degree of Master of Science in Soil Science.

Donald J. Pluth

Dr. D. J. Pluth

Ian W Corns

Dr. I. G. W. Corns

Dan W Gilmore

Dr. D. W. Gilmore

M R T Dale

Dr. M. R. T. Dale

M. J. Dudas

Dr. M. J. Dudas

17 April 2001

Date Approved

Abstract

In this research project the objective was to examine soil-plant relationships, and then develop a soil-site model for the evaluation of mixedwood forests. To do this, the distribution of selected ecological response and soil properties variables was examined along three fire-origin white spruce – trembling aspen toposequences on Gray Luvisols developed in lacustrotill geologic material of west-central Alberta. The models developed through regression analysis suggested concentration of forest floor total N, forest floor bulk density, B-horizon silt content and permanent wilting point were influential soil properties in the study area. The result was two models: 1) leaf area index (LAI) as estimated by a Li-Cor LAI-2000 instrument ($R^2 = 0.62$, MSE = 0.1253, df = 31), and 2) LAI adjusted for the proportion of coniferous species ($R^2 = 0.70$, MSE = 0.2426, df = 31).

Table of Contents

Chapter		Page
1	General Introduction and Literature Review	1
	1.1 Introduction	1
	1.2 Forest-site productivity	2
	1.2.1 Direct methods	3
	1.2.2 Indirect methods	4
	1.3 Soil-site quality evaluation in boreal mixedwood communities	5
	1.3.1 Boreal forest mixedwood communities	5
	1.3.2 Mixedwood forest-site productivity	6
	1.3.3 Landscape-level factors	7
	1.3.3.1 Regional climate	7
	1.3.3.2 Physiography	7
	1.3.3.3 Surficial geology	8
	1.3.4 Site-level factors	8
	1.3.4.1 Hydrological dynamics of landscapes	8
	1.3.4.2 Nutrient dynamics on the landscape	12
	1.4 Spatio-temporal variation	13
	1.5 Research objectives and hypotheses	15
	1.5.1 Summary of the research objectives and hypotheses	17
	1.6 Literature cited	18
2	Study Area and Sampling Design	24
	2.1 Study area	24
	2.1.1 Soils	24
	2.1.2 Regional climate	25
	2.1.3 Vegetation	25
	2.2 Sampling design	26
	2.2.1 Inference space	26

Table of Contents Continued

Chapter		Page
2	2.2.2 Study sites	26
	2.3. Literature cited	33
3	Distribution of Soil Morphological and Texture – Associated properties along Toposequences of White Spruce - Aspen (*Picea glauca – Populus tremuloides*) Mixedwood Communities in West-Central Alberta	34
	3.1 Introduction	34
	3.2 Materials and methods	35
	3.2.1 Study area	35
	3.2.2 Sampling design	35
	3.2.3 Ecological response variables of forest mixedwood communities	36
	3.2.4 Soil properties	37
	3.2.5 Statistical analyses	40
	3.3 Results	41
	3.3.1 Toposequence sites	41
	3.3.2 Slope position	42
	3.3.3 Soil properties and ecological response variables	44
	3.4 Discussion	44
	3.5 Conclusions	49
	3.6 Literature cited	61
4	Post-Fire Forest Floor Development along Toposequences of White Spruce – Aspen (*Picea glauca – Populus tremuloides*) Mixedwood Communities in West-Central Alberta	66
	4.1 Introduction	66
	4.2 Materials and methods	68
	4.2.1 Study area	68
	4.2.2 Sampling design	69

Table of Contents Continued

Chapter		Page
4	4.2.3 Ecological response variables of forest mixedwood communities	69
	4.2.4 Soil properties	70
	4.2.5 Statistical analyses	71
	4.3 Results	72
	4.3.1 Toposequence sites	72
	4.3.2 Slope position	73
	4.2.3Organic C, C/N ratios and net mineralized N and ecological response variables	74
	4.4 Discussion	74
	4.5 Conclusions	76
	4.6 Literature cited	86
5	Modeling of Soil-Site Net Forest Productivity along Toposequences of White Spruce - Aspen (*Picea glauca – Populus tremuloides*) Mixedwood Communities in West-Central Alberta	91
	5.1 Introduction	91
	5.1.1 Selection of soil properties	92
	5.2 Materials and methods	94
	5.2.1 Study area	94
	5.2.2 Sampling design	95
	5.2.3 Ecological response variables of forest mixedwood community	96
	5.2.4 Soil properties	97
	5.2.5 Statistical analyses	98
	5.3 Results and discussion	99
	5.4 Conclusions	104
	5.5 Literature cited	109

Table of Contents Continued

Chapter		Page
6	Synthesis	113
	6.1 Introduction	113
	6.1.1 Identification of high-yielding sites	113
	6.1.2 Advantages of soil-site evaluation	113
	6.1.2.1 Applications in forest management	113
	6.1.2.2 Use in even- and uneven-age forests	114
	6.2 Mixedwood soil-site evaluation in west-central Alberta	115
	6.2.1 Landscape distribution of ecological response variables	115
	6.2.2 Landscape distribution of soil morphological and texture-associated properties	115
	6.2.3 Forest floor development across selected landscapes	116
	6.2.4 Soil-site productivity modeling	116
	6.3 Considerations for the future	117
	6.4 Literature cited	119
	Appendices	122
Appendix I	Soil profile descriptions	123
Appendix II	Ecological response variable and soil physical and chemical property data	143
Appendix III	Two-way ANOVA Interactions	155
Appendix IV	Point sample plot mensuration data	161
Appendix V	Plant community and structure	170
Appendix VI	Regression of soil texture upon Field Capacity	190
Appendix VII	Regression of soil texture upon Permanent Wilting Point	191
Appendix VIII	Regression of soil texture upon Cation Exchange Capacity	192
Appendix IX	Soil property variables selected for regression analysis	193
Appendix X	Soil-site evaluation model for Tree Volume	194
Appendix XI	Soil-site evaluation model for Basal Area	195

Table of Contents Continued

		Page
Appendix XII	Soil-site evaluation model for mean annual Basal Area Increment	196
Appendix XIII	Thesis Glossary	197
	Literature cited	203

List of Tables

		Page
Table 3-1.	Physiographic and soil attributes of the three toposequence sites.	50
Table 3-2.	Summary of forest community and stand attributes of the three toposequence sites in 1998.	50
Table 3-3.	Two-way ANOVA models for the comparison of ecological response variable values among toposequence sites and slope positions.	51
Table 3-4.	Two-way ANOVA models for the comparison of soil property values among toposequence sites and slope positions.	52
Table 3-5.	Comparison of ecological response variables by slope position with pooled toposequence site data.	54
Table 3-6.	Comparison of soil horizon thickness among slope positions and associated two-way ANOVA p-values.	54
Table 3-7.	Comparison of soil bulk density among slope positions, with two-way ANOVA p-values.	54
Table 3-8.	Comparison of soil particle size classes (clay <2 μm, silt 50-2μm, and sand >50μm) among slope positions, with two-way ANOVA p-values.	55
Table 3-9.	Comparison of soil estimated cation exchange capacity among slope positions, with two-way ANOVA p-values.	55
Table 3-10.	Soil pH in distilled water compared among slope positions, with two-way ANOVA p-values.	55
Table 4-1.	Two-way ANOVA models for the comparison of soil property values among toposequence sites and slope positions.	78
Table 4-2.	Organic-C Pools for each slope position by soil horizon and profile total.	80
Table 4-3.	Total N (by mass) with one-way ANOVA p-values for comparison within slope position.	80
Table 4-4.	Total Nitrogen (by volume) with two-way ANOVA p-values for comparison of slope positions.	80

List of Tables Continued

		Page
Table 4-5.	C/N ratios with two-way ANOVA p-values for comparison within slope position.	81
Table 4-6	Rate of net N-mineralization (by mass) with two-way ANOVA p-values for comparison of slope positions.	81
Table 4-7.	Rate of specific net N-mineralization with two-way ANOVA p-values for comparison of slope positions	82
Table 4-8.	Rate of net N-mineralization (by volume) with two-way ANOVA p-values for comparison of slope positions.	82
Table 4-9.	NO_3-N/NH_4-N ratio for forest floor and A-horizons.	83
Table 5-1.	Summary of soil-site evaluation studies (equations not given) for major species in boreal Ontario (Adapted from Carmean, 1994 and 1996b).	105
Table 5-2.	Leaf area ecological response and selected soil variables for soil-site models (eq. 5-1 and 5-2).	106
Table 5-3.	Soil-site model for LAI regressed on selected soil properties (eq. 5-1).	106
Table 5-4.	Soil-site model of LAI adjusted for species composition by basal area (LAI adj. BA) regressed on selected soil properties (eq. 5-2).	107
Table 5-5	Above ground biomass production normalized to annual uptake of nitrogen for boreal deciduous and boreal coniferous species, and coefficients of determination (R^2) for biomass production regressed on nitrogen cycling process (adapted from Cole and Rapp (1981) Tables 6.12 and 6.13).	107

List of Figures

		Page
Figure 2-1.	Landscape management units for the northwest section of the Canadian Forest Products Limited forest management agreement.	28
Figure 2-2.	Topographic map of the study area, including the location of selected toposequence sites.	29
Figure 2-3.	Soils map of the study area, including the location of selected toposequence sites.	30
Figure 2-4.	Grande Prairie Airport 1998 temperature and precipitation data, and the temperature and precipitation climate normals from 1961 to 1990 for the Grande Prairie Airport, Economy Tower and Smoky Tower.	31
Figure 2-5	Schematic depiction of the sampling design for a toposequence site.	32
Figure 3-1.	Leaf area index (LAI) and mean annual basal area increment (BAI) ecological response variables (mean ± SE) compared among toposequence sites according to slope position.	56
Figure 3-2.	Volumetric water content of a) forest floor in late-July and mid-August. For b) A-horizon, c) B-horizon and d) C-horizon, volumetric soil water content in late-July and early-October, and estimated available water capacities between -33 and -1500 kPa matric potential to a mineral profile depth of 1.20 m.	57
Figure 3-3.	Cumulative available water capacity (AWC) to 1.20 m depth at the crest, upper, middle and toe slope positions. Overlaid is the available soil water for the profile at each slope position during early-October.	58
Figure 3-4.	Ecological response variables regressed on selected soil physical properties.	59
Figure 3-5.	Frequency of root size, as a proportion of the total number of subhorizon observations within a size class, sorted by abundance classes for the a) forest floor, b) A-horizon, c) B-horizon, d) C-horizon to a mineral soil depth of 1.20 m.	60

List of Figures Continued

		Page
Figure. 4-1.	Cumulative organic-C by depth within soil profiles for each slope position.	84
Figure. 4-2.	Ecological response variables regressed upon soil N parameters.	85
Figure 5-1.	Scatter plot diagrams of the observed versus predicted a) leaf area index (LAI; eq. 5-1) and b) leaf area index adjusted for the proportion of coniferous species in the stand, by basal area (LAI adj. BA; eq. 5-2).	108
Figure 6-1.	Schematic depiction of a toposequence site with mean (± SE) values for selected soil and leaf area ecological response variables by slope position.	118

List of Equations

Equation		Page
3-1	Leaf area index adjustment for the proportion of coniferous species in the mixedwood stand (LAI adj. BA), $m^2\ m^{-2}$.	37
3-2	Field capacity; θm (ψ @ -33 kPa), g $100g^{-1}$.	39
3-3	Permanent wilting point; θm (ψ @ -1500 kPa), g $100g^{-1}$.	39
3-4	Cation exchange capacity; CEC, cmol(+) kg^{-1} at pH 7.	40
3-5	Two-way ANOVA model.	40
4-1	Two-way ANOVA model.	72
5-1	LAI soil-site evaluation equation, $m^2\ m^{-2}$.	99
5-2	LAI adj. BA soil-site evaluation equation, $m^2\ m^{-2}$.	99

Chapter 1

General Introduction and Literature Review

1.1 Introduction

The influence of soil properties on tree growth has been apparent for a long time. One reason soil-plant growth relationships are studied is to determine factors limiting growth. Once the critical factors limiting growth are understood soil amendments may be prescribed to improve productivity. Use of soil properties to estimate the ability of a site to grow trees is referred to as soil-site quality evaluation. This is an alternative to the common method of determining site quality, site index, which is not easily applied in mixedwood (uneven-aged) forests as it is in even-aged forests.

Site index is the maximum tree height attained by a tree of a given species, and it assumes that the tree has not been suppressed by an overstory. Variation of tree height-age in mixedwood forests complicates the assumptions normally made for even-aged site index measurements. Identifying a tree in a mixedwood forest that meets the required assumption of site index is difficult. In *Populus–Picea* mixedwood forests the younger *Picea* trees occupy a subdominant crown position, and at some stage experience competition for space.

An alternative productivity expression to site index is net primary productivity. Net primary productivity is a fundamental measure of plant productivity (Soil Science Society of America, 1998b). Understanding relationships between net primary productivity and soil properties may provide useful mathematical models to estimate site quality. Knowledge of these soil-net primary productivity relationships would improve forest management by contributing to the:

1. Understanding of the distribution of key soil properties in the landscape of selected mixedwood communities;
2. Understanding of the soil-plant relationships limiting the growth of mixedwood communities;
3. Evaluation of mixedwood community net primary productivity based on landscape soil properties; and
4. Sustainable mixedwood forest management by furnishing a model to monitoring soil quality through mixedwood community net primary productivity.

A predictive model that uses soil properties to estimate mixedwood net primary productivity would identify high yielding sites within uneven-aged forests. Locating and utilizing highly productive land is

essential for wise forest management, particularly in Alberta where the boreal ecoregion occupies two-thirds of the province (Hostin and Titus, 1996), and nearly one-fourth of the province's forest type is mixedwood (Canadian Forest Service, 2000). High yielding forest areas generate more economically desirable forest biomass in a given rotation, and are potentially more responsive to silvicultural tending. The concept of locating and using high yield forest areas is similar to the idea adopted by early agriculturalists to maximize the yield of their crops.

Defining relationships between critically influential soil properties and uneven-aged forest productivity could furnish a model for monitoring and assessing forest practices. Monitoring influential soil properties over the duration of a management plan could ensure long-term sustainable practices are being employed. This information can be used for certification in sustainable resource initiatives, such as the international Forest Stewardship Council (FSC) and International Organization for Standardization (ISO) as well as the national Canadian Standards Association (CSA) (Canadian Forest Service, 2000).

1.2 Forest-site productivity

Plant community diversity within the boreal forest of Canada makes wise and responsible forest management difficult. Evaluation of site productivity makes it possible to stratify parts of the boreal forest to aid in decision-making. Currently, sensible decision-making means the best use of renewable natural resources while simultaneously maintaining the diversity and integrity of the system.

Identification of the potential of a site to grow trees could help achieve the goal of forest management to utilize forest resource while maintaining it for future generations. Areas that show greater potential to grow trees are said to have higher site quality. In other words, a high quality site (for wood fiber production) would grow large, healthy trees, relatively quickly and cheaply compared to other sites. The intensification of forest management on an area of high site quality could provide the bulk of the resources required by society, and leave other areas undisturbed by human involvement.

The several methods of evaluation of site quality within a boreal forest can be organized into two groups:

1. Direct site evaluation methods are based on some measurement of yield.
2. Indirect site evaluation methods rely on identification of key site indicators and knowledge of their relationship to yield.

1.2.1 Direct methods

The most commonly used and widely accepted method of direct evaluation of site quality is based on the height of dominant or co-dominant trees at a reference age (Carmean, 1996a). "The height of free-grown trees, individuals that have grown from the time of their establishment without suppression by an overstory canopy of a given species of a given age, is more closely related to the capacity of a site to produce wood than any other one measure" (Barnes *et al.*, 1998). The expression using tree height at a reference age as an indication of site quality is referred to as Site Index (SI). The reference age can be arbitrarily chosen, but usually reflects the likely rotation-age for a tree species. It is reliable in even-aged stands, where each individual tree is competing fairly with its neighbours for site resources. Unfortunately site index requires unsuppressed trees of the given species, and is therefore not easily applicable to all boreal forest stands.

Site index is not easily applied to mixedwood stands because the growth history of trees is not usually known. That is, the duration of growth suppression for an individual plant is unknown. If the stand history were known, the yield data could be used to evaluate the quality of the site by itself. The stand history can be determined by annual records or stem analysis. The former is not commonly available in Canada's boreal forest, and the latter is destructive, time consuming and costly.

Site index is used to evaluate site quality from site-index curves. The curves show the tree height at a given age in relation to the best and worst possibilities known to exist. There are two types of site-index curves: harmonic and polymorphic. Harmonized and polymorphic curves express dominant tree height with age, but harmonized site-index curves assume that site differences will be apparent at an early age (Barnes *et al.*, 1998). The result is nearly parallel growth curves for a site. In contrast, polymorphic site-index curves also consider the effect of site conditions as a tree grows. That is, polymorphic curves account for differences among sites as trees age and grow to fully utilize site resources. Polymorphic curves are closely related to soil conditions (Barnes *et al.*, 1998).

Other direct methods of determining site quality are species comparison and growth-intercept. Species comparison uses an estimate of yield, such as site index, of one species to estimate the yield of another on the same site. The growth-intercept method utilizes the internodal distance to estimate the mean annual increment of height (*i.e.*, a form of yield) for a site. This method is also "old and well established" (Barnes *et al.*, 1998), but unfortunately is only usable on conifers with distinct whorls.

1.2.2 Indirect methods

Indirect site-quality evaluation can be used to estimate site index too, but it can utilize a more fundamental measure of productivity. Indirect site-quality evaluation is accomplished using proxy information to estimate site quality through mathematical expressions. The mathematical expressions are typically called site-quality evaluation equations.

The use of fundamental measures of productivity (*i.e.*, the ecological approach) to evaluate site quality can be more useful than expressions derived from site index. Indirect methods based on fundamental measures of plant community productivity can potentially be applied in either even-aged or uneven-aged stands since they do not necessarily require a knowledge of tree growth history or a given tree species to be present.

Site indicators that have been researched include understory vegetation, soil fauna, and environmental factors. Understory vegetation can be used as a proxy of site conditions in order to estimate potential site productivity (Corns, 1984; La Roi *et al.*, 1988; Strong *et al.*, 1991). However, the use of vegetation as a proxy indicator for the quality of a site is complicated by the consideration that species or species groups may or may not be found on a particular site due to stand history and succession on sites within the boreal forest. Use of soil biota is the second type of proxy information to indirectly evaluate forest-site quality. For example, earthworm biomass for specific species has been related to forest production (Muys and Granval, 1997). The third type of indirect site-quality evaluation relies upon the environmental factors such as regional climate, physiography (topography), and surficial geology (soil parent geologic material). These three factors are also soil forming factors (Soil Science Society of America, 1998a).

Regional climate is not typically a consideration because of its relative uniformity at a landscape level, but physiography and surficial geology can be unique to sites within a region. Physiography influences microclimate, and both physiography and surficial geology influence the availability of site resources. So, the relationship between the variability of physiographic and surficial geologic components, and the potential productivity of a forest-site is important. It is important for management planning and operational forestry, especially since it is the accumulation of the estimated future yield for many sites that determines the maximum annual allowable cut that can be sustained indefinitely, by a forest.

Physiography and surficial geology as soil forming factors influence soil properties (Soil Science Society of America, 1998a). The variation of soil properties by physiographic position, within the same

surficial geologic material is called a soil catena, and it can effect plant community productivity. In the 18th century, the German chemist Justus Von Liebig was credited with relating different rates of plant production and variation of soil properties by the addition of inorganic soil elements (Brady, 1990). This conclusion lead to the development of the law of minimum. The law that states the growth of a plant is limited by the least abundant essential factor. More recently, the importance of soil is still identified as crucial to sustainable site productivity. Much more detail is understood about the relationship between improved productivity and soil physical properties, soil organic matter, and nutrient content and cycling rates (Kimmins, 1996).

1.3 Soil-site quality evaluation in boreal mixedwood communities

1.3.1 Boreal forest mixedwood communities

In boreal forest mixedwood communities changing inter- and intraspecies competition for site-specific resources (*e.g.*, soil water, nutrients, and space), as well as wildfire, keep stand structure and composition in a state of constant flux. As a result, succession in the boreal mixedwood forest is a complex subject, and is briefly discussed in order to explain in general terms: 1) the stand age-structure of boreal mixedwoods, which is the reason site index is not as easily applied to mixedwoods as it is to even-aged stands; and 2) the tree species commonly involved in fire-origin boreal mixedwood stands of Alberta.

Wildfire in the boreal forest is an important factor of stand history, especially in the western boreal forest. It creates plant community variability at both landscape and site levels. Wildfire causes a wide degree of variation because of the size, shape, and degree of effect (severity). The severity of a fire influences the extent of alterations to vegetation and forest floor, and dramatically changes the soil temperature and drainage that are important considerations for the type of seedbed available to pioneer plants. In effect, wildfire dramatically changes site nutrient storage and cycling. Wildfire is important because it is responsible for partially or fully resetting successional pathways. "The western boreal forest is a disturbance forest, usually maintained in youth and health by frequent fires to which all species, with the exception of fir, are nicely adapted." (Rowe, 1961).

Succession in the boreal forest can only have meaning within a given area and given environment, due to the potential for variability (Rowe, 1961). That means each site is unique; it is difficult to predict the configuration of possible stages leading to a final and stable plant community (*i.e.*, commonly referred to as the climax stage), if one even exists. An educated guess for possible seral stages would

have to be based on local species (seed sources), sociology of those species (species ecology), and pre-existing local vegetation patterns. Typical succession in the boreal forest involves establishment of pioneer species on a site after a wildfire. The pioneer species could be aspen (*Populus* spp.), larch (*Larix* spp.), birch (*Betula* spp.), pine (*Pinus* spp.) or any other species that rapidly proliferates and flourishes in direct sunlight. Later openings in the community occur after the death of unhealthy individuals. Death of individual trees in the community releases site resources for the next seral species which are shade tolerant, such as spruce (*Picea* spp.) and fir (*Abies* spp.). However, frequent wildfires of varying intensity, size and shape often keep the boreal forest site in early successional stages.

In the western boreal forest there are many species, each with a potential to be involved in a plant community at different successional stages. Most of the expanse of the western boreal forest is coniferous, although Alberta has considerable area in mixedwood communities (Pojar, 1996). Dominant conifer trees in the western boreal forest are spruce (*Picea glauca* (Moench) Voss and *Picea mariana* (Mill.) BSP), fir (*Abies balsamea* (L.) Mill. and *Abies lasiocarpa* (Hook.) Nutt.), pine (*Pinus banksiana* Lamb. and *Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.), and larch or tamarack (*Larix laricina* (Du Roi) K. Koch). Dominant hardwoods in the western boreal forest are black or balsam poplar (*Populus balsamifera* L.), trembling aspen (*Populus tremuloides* Michx.), white or paper birch (*Betula papyrifera* Marsh.), green alder (*Alnus crispa* (Ait.) Pursh.), river alder (*Alnus tenuifolia* Nutt.), and willow (*Salix* spp.). In Alberta white spruce and aspen in uneven-aged mixedwood communities are abundant in the northern two-thirds of the province.

1.3.2 Mixedwood forest-site productivity

In boreal mixedwood forest communities the uniqueness of stand history restricts the use of site index. Proper use of site index requires unsuppressed trees that are difficult to identify in a mixedwood forest. Therefore measures of forest productivity less influenced by stand history are preferred. Net primary productivity is a fundamental measure of site productivity. Net primary productivity is the rate of accumulation of plant biomass (assimilation of C) after consideration of losses due to consumption and respiration.

In general factors controlling net primary productivity in the boreal forest community are regional climate, surficial geology, and physiography. These are conditioning factors that envelop complex systems of interactions affecting plant growth. Ultimately regional climate, surficial geology and physiography influence tree growth by limiting photosynthesis, the source of energy for tree growth

(Fritts, 1976). These limit photosynthesis through their influence on solar radiation, temperature, precipitation, atmospheric gases, and ultimately landscape soil water and nutrient dynamics.

1.3.3 Landscape-level factors

1.3.3.1 Regional climate

Plant communities in the boreal forest form a mosaic that is caused in part by variations of regional climate, surface geology, and physiography. These factors operate in tandem with the others and at different scales.

At the landscape level the forest community is influenced by regional climate. In the boreal forest of North America regional climate has a major influence on the type of plant community and rate of production (*i.e.*, productivity). Regional climate is affected by solar radiation and landscape-level weather patterns resulting from bodies of water, landmasses, and the circulation of air masses. These influence the landscape-level zonation and plant growth of the boreal forest primarily through temperature and precipitation patterns. The influence of regional climate in Canada can be seen by the change of forest regions from south to north: Boreal - Forest and Grass to Boreal – Predominantly forest to Boreal - Forest and Barren as shown in the forest regions map by Rowe (1972), and presented by Farrar (1995). However, the use of regional climate in operational forestry is limited. More critical are relatively smaller-scale factors of physiography and surficial geology.

1.3.3.2 Physiography

Physiography acts upon boreal forest diversity at a smaller scale than regional climate by interacting with it, and modifying seasonal patterns of received solar radiation and temperature. Physiography encompasses slope aspect and gradient. These factors can be highly variable over relatively short distances mainly as a result of bedrock, and/or surficial deposits from extensive advances and retreats of glaciers, particularly during the Pleistocene epoch (*ca* 10 000 a to 1.8 Ma or 2.4 Ma, depending on criteria used to classify this epoch). Slope aspect and gradient are especially important in the western boreal forest due to the latitude, which affects the duration and the angle of incident solar radiation. The duration of solar radiation is critical to plant growth. Physiography also enhances the variability of the soil environment of the boreal forest by modifying hydrological and biogeochemical processes.

1.3.3.3 Surficial geology

Similar to physiography, surficial geology further modifies the boreal forest community diversity at a smaller scale than regional climate by interacting with it and physiography. The advance and retreats of glaciers on the Canadian landscape have left a large range of parent geologic materials. These parent materials are the foundation for soils, in which climate and other soil forming factors are expressed. Morainal material or lacustrine material has been deposited in some places, and fluvial or eolian parent material in other places. The variation in sorting of particle sizes in these parent materials can influence plant growth (Järvinen *et al.*, 1993). In addition to the variety of parent materials the thickness of the surficial deposits is also highly variable. In some cases there can be veneers of lacustrine over morainal parent material, or other combinations. Finally, mineral composition of the parent material has significant influence on vegetation development and mineral soil spatial heterogeneity even at the site level (Järvinen *et al.*, 1993).

1.3.4 Site-level factors

Regional climate, physiography and surficial geology influence boreal forest communities. Local or site-level conditions operate in relatively small areas compared to regional climate, physiography and surficial geology. At a site level the interaction of regional climate, physiography and surficial geology occurs, and influences landscape soil processes.

1.3.4.1 Hydrological dynamics of landscapes

The interaction of surficial geology and physiography is a major influence in the soil processes at work in the landscape. The result of the interaction of surficial geology and physiography in this study is referred to as landscape processes. In the boreal forest water and nutrient dynamics throughout the landscape are a driving force in boreal forest diversity at a site level.

Landscape soil water dynamics is highly variable because of the large number of interacting site characteristics involved in the flux and distribution of soil water. In eco-hydrology a distinction has been made between site characteristics that influence soil water flux and spatial distribution, and soil properties directly affecting plant growth (Klijn and Witte, 1999). The former group is relatively *conditional* site factors, and the latter group is called relatively *operative* factors. Landscape water dynamics have been categorized into water flux inputs, flux outputs and storage in order to simplify how conditional site factors influence soil water.

Initially the soil water input flux is precipitation: rain, snow, hail, fog, *etc*. Considering the form of precipitation, the variability of flux and distribution into the soil water element of the ecosystem will be great. The variability of soil water input flux is dependent upon seasonal patterns of the regional climate and the specific physiographic position influencing duration and incident angle of solar radiation. The term microclimate is used to describe the interaction of regional climate and physiographic position. Local microclimate affects the supply of water and energy to initiate flux and redistribution of water in the soil.

Soil water outputs are essentially a redistribution of the soil water inputs with variable distribution of flux density caused by the interaction of surficial geologic material characteristics, physiographic position, as well as the effect of the prior landscape soil processes on current soil properties. A simple list of soil water output variables should include surface evaporation, transpiration by plants, surface and subsurface flow, and percolation.

Use of the term evaporation can refer to water output as a result of precipitation intercepted by plant community canopy and forest litter. During the summer, evaporation is a considerable output in the boreal forest (Metcalfe and Buttle, 1999). In the boreal forest evaporation output from precipitation intercepted by the plant community canopy is a larger source of water output flux density and distribution than evaporation output from forest floor litter interception (Ulrich *et al.*, 1981). Evaporation from forest litter interception is less because solar radiation has been greatly reduced by the plant community canopy, among other reasons. Research has suggested soil water evaporation from closed canopy forest and agricultural land cover types in Alberta, Canada is not significant (Biftu and Gan, 2000). Evaporation of intercepted precipitation diminishes soil water input, and therefore indirectly alters soil water dynamics.

Use of the term evaporation can also be applied to soil water vapour lost directly from the soil. Evaporation redistributes soil water through pathways with variable flux densities, and ultimately causes complex water potential energy gradients. Water energy potential gradient is referred to as hydraulic potential, and it develops as a result of water evaporation from the soil surface or by other soil water output variables. In the boreal forest mineral soil water evaporation is often limited by thermal insulation and drastic change in capillarity at the interface of dissimilar layers; particularly the forest floor material accumulated on a site and the mineral soil (Ulrich *et al.*, 1981). Water storage in low physiographic positions in the boreal forest and subsequent evaporation are fundamental to local landscape water balances (Metcalfe and Buttle, 1999).

Transpiration as an important direct soil water output is caused by the hydraulic gradient between the soil and atmosphere through plants, known as the soil-plant-atmosphere continuum. Transpiration is sometimes referred to as productive evaporation. In the boreal mixedwood forests of central Saskatchewan the canopy structure and density was observed to influence variability in soil water (Elliott *et al.*, 1998). The flux density of transpiration is largely dependent upon the intensity of the hydraulic gradient as long as water in the root zone is sufficient for plant production. It has been suggested that transpiration from mature boreal mixedwood forest communities of central Canada results primarily from the supply and loss of leaf tissue water (Fredeen and Sage, 1999). However, when soil water becomes limited to roots, tree physiological processes dominate the rate of transpiration (Ulrich *et al.*, 1981).

A boreal forest study in central Sweden indicated tree transpiration was the dominant component in evapotranspiration on a daily basis during the period between 16 May and 31 October 1995 (Grelle *et al.*, 1997). Evapotranspiration is the term used when the "principles applied to transpiration from individual trees are extended to a whole stand and then combined with a consideration of evaporation from the canopy and litter to estimate the total flux of water vapour from a forest" (Waring and Schlesinger, 1985). In another study within the boreal forest of central Sweden maximum daily rates of evapotranspiration were typically 4 mm d^{-1} in mid-summer and was 0.5 mm d^{-1} during the winter period from November to March (Grelle *et al.*, 1999). In an aspen stand within the boreal forest of central Saskatchewan, maximum daily evapotranspiration rate was 5 to 6 mm d^{-1} near the end of July, 1994 (Black *et al.*, 1996).

In addition to evaporation and transpiration there are three other hydrological outputs: surface and subsurface movement of water laterally across the landscape (runoff) and percolation downward through the soil. These outputs affect free soil water through the interaction of surficial geologic material, genetic horizon characteristics and physiographic position.

Surficial geologic material and the conditions of the genetic horizons causes variability in the distribution and flux density of soil water vertically and horizontally through the distribution of pore sizes involved in capillarity, generally 0.2 μm to 50 μm in diameter (Ulrich *et al.*, 1981). The flux density of percolation due to the distribution of pore sizes is called the hydraulic conductivity. During periods when there is a large input flux density some soil water will move laterally on top of the soil horizon. This occurs when percolation flux density does not exceed the input flux density of soil water. During the spring snowmelt, lateral flow of water at the site level in the boreal forest of northern Manitoba was a large output (Metcalfe and Buttle, 1999). Variations in snow water equivalent, rainfall timing and magnitude, and thaw depth caused annual variations in horizontal soil water flux.

Physiographic position influences the amount and duration of solar radiation received, the rate of thaw and evaporation of precipitation, and therefore affects soil-plant-atmosphere hydraulic gradients. The influence of physiographic position may be supported by evidence that south-facing slopes under aspen canopies in central Alberta, west of Edmonton, had higher soil temperatures and lower water contents during the growing season than north-facing slopes (Macyk *et al.*, 1978). The interaction of surficial geologic material and physiography can be strongly expressed by the characteristics of soil horizons. The result of diverse soil characteristics is variation of the distribution flux densities for the surface and subsurface runoff as well as percolation of soil water from high to low landscape positions. The movement of soil water from high to low landscape positions is gravity driven, *i.e.*, along a pathway of decreasing hydraulic gradient. Regular patterns of gravity-driven ground water flux from higher physiographic (recharge) positions downward along a toposequence (throughflow) toward the bottom physiographic (discharge) positions act as a "conveyor belt" (Tóth, 1999). Discharge areas usually have higher nutrient concentrations than surrounding areas (Klijn and Witte, 1999). The effects of ground-water discharge may be most strongly expressed in the capillary fringe, a region close to the ground-water table where the water potential is nearest to zero. The capillary fringe is particularly important at the toe slope position were it is nearest to the mineral soil surface and is easily accessible to plants.

Water input and output flux densities, as well as storage determine soil water balance. Storage of soil water is considered to occur when the water that remains in the soil is not influenced by gravitational potential energy. Generally, this occurs when gravitational potential (Ψg) is equal to the matric potential at -33 kPa (Ψm @ -33 kPa); at this point water flux density of the soil surface and subsurface runoff, as well as percolation outputs cease, ecologically speaking. Evidence does exist that soil water is never truly at rest (Ulrich *et al.*, 1981). Even at $\Psi m < -33$ kPa, redistribution of soil water as unsaturated flow will continue in response to hydraulic gradients between plant community roots or soil surface, and stored soil water as a result of transpiration or evaporation. It is accepted that plant roots are considered to be able to draw on stored soil water down to -1500 kPa, at which point plants wilt irreversibly (Ulrich *et al.*, 1981).

Soil water dynamics is a large contributor to the spatial variation of soil properties in the landscape. Variation occurs in the landscape as a result of the interaction and distribution of input and output flux densities, and stored soil water. However, one of the largest factors influencing soil water dynamics after input flux is landscape position. Landscape position creates a hydraulic gradient with highly variable flux density distribution between upper and lower landscape positions. Therefore landscape position causes variation in other soil processes along a topographic sequence.

1.3.4.2 Nutrient dynamics on the landscape

Nutrient element dynamics is highly influenced by water dynamics that redistribute chemicals (Klijn and Witte, 1999), as mentioned above. Nutrient element gradients exist throughout the landscape as a result of the interaction and distribution of input and output flux densities of nutrient ions and the capacity of the soil for nutrient storage.

Nutrient element inputs are the result of the decomposition of organic matter, leaching, sedimentation and weathering of primary minerals, and possibly atmospheric deposition or fixation by organisms in the case of N (*i.e.*, conversion of N_2 to NH_4^+). Input of nutrients is spatially and temporally variable for many reasons. For example, fluxes in organic matter nutrient element input are the combined effect of rate of organic matter addition to the soil, organic matter composition, the rate of decomposition/mineralization from organic compounds into plant absorbable nutrient ions.

In the floor of the boreal forest, wet and cool landscape positions typically retain organic matter in largely undecomposed states (Pojar, 1996). In boreal forest peatlands of central Alberta, researchers found increased availability of N with the lowering of water table, and suggested increased soil-surface temperatures and an improved soil water-aeration relationship as the cause (Mugasha *et al.*, 1993). Soil water and temperature patterns are believed to be highly associated with community productivity in the boreal forest (Kimmins, 1996). Extreme water contents and cold temperatures limit aerobic microbial activity thus slowing decomposition rates (Hobbie, 1996; Trettin *et al.*, 1996; Hobbie *et al.*, 2000) and reducing soil nutrient input.

Nutrient element outputs are largely due to transport and absorption of nutrient elements. Transportation or root absorption of nutrient elements depends on water dynamics. Nutrient elements move through the soil as a result of soil water, either by mass flow of particles in suspension or ions in solution. Suspended particles can be moved downward by percolation as in the case of luvisolic soils, *i.e.*, translocation of clay, Fe, Al and/or organic matter.

Nutrient elements in solution may be transported by diffusion across thermal and concentration gradients, and by mass flow (Ulrich *et al.*, 1981), *e.g.*, NO_3^- (Paul and Clark, 1996). When nitrification converts NH_4^+ to NO_3^-, N can be lost from soil space easily accessible to roots since nitrate is readily mobile in soil solution. Nitrogen in the boreal forest is a vital component of the ecosystem (Kimmins, 1996). Its influence upon net primary productivity is through species' photosynthetic efficiency (PE), which is the ratio of gross primary production to photosynthetically active radiation (Addicott, 1999).

Upper and lower landscape positions have very different water and nutrient contents. Lower slopes may be on the receiving end of water and nutrients mobilized from higher slope positions. Thus there are very important differences between soil processes at upper and lower landscape positions.

Root absorption of nutrient elements is the other major soil output. Root absorption of nutrient elements is affected by water dynamics too. Nutrient flux density to roots is influenced by the hydraulic and osmotic gradients between the soil nutrient pool and the root surface.

Nutrient elements can be stored in the soil as well. Nutrient elements are stored on negatively charged exchange sites that bind with nutrient cations. Nutrient element input and output fluxes, and pH are responsible for the amount of nutrient elements stored on cation exchange sites, instead of being lost from the root zone of plants by leaching.

At the site-level soil processes develop a large amount of spatial variation in the boreal forest. Soil water dynamics are strongly associated with physiography. Furthermore the distribution of water input and output flux densities along a topographic sequence influences nutrient dynamics. Together, landscape soil and water nutrient dynamics may cause a large amount of spatial variability in soil properties, even at a microsite level. In order to develop soil-site evaluation equations researchers must deal with the spatial and temporal variation of soil properties.

1.4 Spatio-temporal variation

The value of soil-site evaluation equations depends upon the ability of the predictor variables to explain the variation in the estimate of plant productivity. Variation comes from many sources including experimental error. Experimental error is a term that describes the variation existing among experimental units that experienced the same treatment (Steel and Torrie, 1980). Experimental error would include variation in soil property estimates resulting from measurement error during laboratory analysis, as well as the inherent variability among individual samples from a population.

Inherent variation in soil properties can be spatial and temporal. In particular, time is recognized as a soil forming factor (Soil Science Society of America, 1998a). An example of temporal variation is the rate of availability of plant nutrients. In the boreal forest, the rate of availability of N is important (Kimmins, 1996; Nasholm *et al.*, 1998). Availability of N is seasonally variable. The highest rates of N availability occur in the spring and summer (Nadelhoffer *et al.*, 1984; Huang and Schoenau, 1997; Knoepp and Swank, 1997). Furthermore, boreal forest floor N attributes vary with vegetation type and age (Fyles and McGill, 1987). In the A-horizon N attributes are related to previous and present forest

stand conditions and in the B-horizon they are independent of vegetation suggesting control by even longer term N cycling.

In addition to temporal variation, soil properties have inherent spatial variability. According to Cameron *et al.* (1971) "the largest and most significant variation in soil testing is no doubt spatial". Frankland (1963) commented that large spatial variation could obscure monthly (temporal) variations. Inherent soil property spatial variability was a concern in many studies, *e.g.*, Frankland *et al.* (1963), Ike and Clutter (1968), Cameron *et al.* (1971), Lowe (1972), Blyth and MacLeod (1978), Quesnel and Lavkulich (1980), Amponsah, (1998), and Amponsah *et al.* (1999).

Inherent spatial variation of soil properties is partly a result of interacting soil-forming factors including: plant community (vegetation), regional and microclimate, surficial geology (parent material), and physiographic position (topography). Variability of soil properties across the landscape is expected due to the influence of soil forming factors on hydrological dynamics and the horizontal and vertical redistribution of nutrients (Klijn and Witte, 1999). Even within site a high degree of variability has been identified for several measures of N availability (Gross *et al.*, 1995). In the case of soil N availability spatial variation presents a considerable obstacle for obtaining an appropriate sample (Keeney, 1980).

In several sitka spruce (*Picea sitchensis* (Bong.) Carrière) stands in Scotland, forest floor total N has mean coefficients of variation (CV) of 4% to 12%; requiring about 3 to 9 samples (0.01 ha plots) to reach 95% confidence limit with 10% allowable error (Blyth and MacLeod, 1978). For extractable cations such as potassium, calcium and magnesium CVs were greater. In other studies soil properties such as cation exchange capacity and pH were relatively less variable, compared to exchangeable cations (Lowe, 1972; Quesnel and Lavkulich, 1980).

Given the considerable spatio-temporal variability in soil properties, care must be taken when using statistical tests. The power of a statistical test lies in the experimental error. Ultimately the only way to improve the power of a test is to reduce the variation in experimental error by (Steel and Torrie, 1980):

1. Reducing inherent variability within the sampling units; or
2. Refine the design of the test to account for variation previously included in experimental error.

In eastern Finland a study of glaciofuvial material indicated soil particle size sorting as an important factor influencing plant growth (Järvinen *et al.*, 1993). Particle-size distribution influences soil water retention (Petersen *et al.*, 1996) and cation exchange capacity (Helling *et al.*, 1964; St. Arnaud and Sephton, 1972; Petersen *et al.*, 1996; Curtin and Rostad, 1997). Soil-site evaluation equations in

northwestern Ontario for several boreal tree species were stratified by parent geologic material (Carmean, 1996a; Carmean, 1996b) to reduce the effect of spatial variation.

1.5 Research objectives and hypotheses

Soil-site evaluation equations relate soil properties to the ability of the site to produce tree biomass. Use of soil-site evaluation equations appears to be a method that is capable of estimating forest-site quality in boreal forest mixedwood stands. Previously studies using soil-site evaluation equations have focused on even-aged stands using site index as the measure of forest-site quality. However site index is not well adapted to use in boreal mixedwood plant communities. The stand history of boreal mixedwood plant communities is too complex for site index; these plant communities require a more fundamental approach to predict forest-site quality.

In this research project the primary objective was to develop mathematical relationships for the evaluation of boreal forest mixedwood community productivity in west-central Alberta. Measures of forest-site quality were regressed on soil property variables to achieve this objective.

Several measures of forest-site quality that had potential usefulness in boreal forest mixedwood communities were selected. This precluded the use of site index. The selected measures of forest-site quality are termed ecological response variables because they reflect site conditions through plant production. The ecological response variables considered were basal area, basal area increment, and leaf area index.

Soil-site evaluation equations attempting to estimate net plant community productivity require consideration of many soil properties with substantial spatial variation. Identifying patterns of landscape processes may help recognize uniformity in distribution of soil properties across a landscape to reduce spatial variation and discover biological connections between influential soil properties and forest-site net primary productivity of boreal mixedwoods. The landscape distribution of selected soil properties was examined along toposequences. This approach was meant to stratify the landscape into site-quality classes defined by soil properties resulting from landscape processes.

After examination of the distribution of soil properties the relationships between forest-site quality and selected soil properties were investigated. Soil-site evaluation equations were developed using ecological response variables for which soil properties (predictor variables) explained the greatest amount of variation while appearing to have a meaningful fundamental biological association with net primary productivity of boreal mixedwood communities.

Inherent in the research objectives are three research hypotheses. The first research hypothesis is that our proxy variables for forest-site net primary production (ecological response variables) are not similar among physiographic positions. If the null hypothesis were true then the selected ecological response variables do not vary by slope position. In this case, landscape processes resulting from the influence of soil forming factors and their influence on soil properties cannot explain any variation in ecological response variables. The second research hypothesis is that selected soil properties are not similar among physiographic positions. If the null hypothesis were true then the distribution of soil properties cannot explain any variation in ecological response variables. The third research hypothesis is directly related to the primary objective of this project. The third research hypothesis is that selected soil properties will describe the variation in ecological response variables. If the null hypothesis were true, then ecological response variables are not affected by site conditions, particularly soil conditions developed from soil forming factors.

1.5.1 Summary of research objectives and hypotheses

Objectives of this project are:

1. To examine soil chemical and physical properties along a toposequence and infer landscape processes operating in the boreal mixedwood forest in west-central Alberta;
2. To consider the relationships between forest productivity proxy variables and soil chemical and physical properties; and finally
3. To develop models for prediction of forest productivity using selected quantitative soil predictor variables.

Research hypotheses of this project are:

1. Ecological response variables at each landscape position along the toposequence are not similar due to differences in soil processes within the landscape;
2. Selected soil properties at each landscape position along the toposequence are not similar due to differences in soil processes within the landscape; and
3. Soil properties will provide an indication of net mixedwood forest productivity along the toposequence.

1.6 Literature cited

Addicott, J. F. 1999. Biology 208 - Principles of Ecology - Fall 1999 Section A1. http://gause.biology.ualberta.ca/bio208.hp/sections/addicott/glossary/definitions/photosynthetic_efficiency.htm. Accessed: 28 December, 2000. Univ. of Alberta, Dept. Biol. Sci.

Amponsah, G. I. 1998. Forest soil characteristics and variability under teak (*Tectona grandis* Linn. F) plantations and national forests in Ashanti region, Ghana. Unpubl. M. Sc. thesis. Lakehead Univ., Thunder Bay, Ontario. 88 pp.

Amponsah, G. I., W. L. Meyer, and G. H. Murchinson. 1999. Soil sampling size estimates for soils under teak (*Tectona grandis* Linn. F) plantations and natural forests in Ashanti region, Ghana. Can. J. Soil Sci. **80**: 327 - 336.

Barnes, B. V., D. R. Zak, and S. R. Denton. 1998. Forest ecology. 4th. John Wiley & Sons, New York. 774 pp.

Biftu, G. F., and T. Y. Gan. 2000. Assessment of evapotranspiration models applied to a watershed of Canadian prairies with mixed land-uses. Hydrol. Process. **14**: 1305 - 1325.

Black, T. A., G. DenHartog, H. H. Neumann, P. D. Blanken, P. C. Yang, C. Russell, Z. Nesic, X. Lee, S. G. Chen, R. Staebler, and M. D. Novak. 1996. Annual cycles of water vapour and carbon dioxide fluxes in and above a boreal aspen forest. Glob. Chang. Biol. **2**: 219 - 229.

Blyth, J. F., and D. A. MacLeod. 1978. The significance of soil variability for forest soil studies in north-east Scotland. J. Soil Sci. **29**: 419 - 430.

Cameron, D. R., M. A. Nyborg, J. A. Toogood, and D. H. Laverty. 1971. Accuracy of field sampling for soil tests. Can. J. Soil Sci. **51**: 165 - 175.

Canadian Forest Service. 2000. The state of Canada's Forests 1999-2000 Forests in the new millennium. Nat. Resour. Can., Can. For. Serv., Ottawa. Fo 1-6/2000 E. 120 pp.

Carmean, W. H. 1996a. Forest site-quality estimation using forest ecosystem classification in Northwestern Ontario. Environ. Monit. Assess. **39**: 493 - 503.

Carmean, W. H. 1996b. Site-quality evaluation, site-quality maintenance, and site-specific management for forest land in northwest Ontario. Northwest Sci. and Technol., Ont. Min. Nat. Resour., Thunder Bay. NWST tech. rept. TR-105. 111 pp.

Corns, I. G. W. 1984. Vegetational indicators as independent variables in forest growth prediction in west central Alberta, Canada. For. Ecol. Manage. **9**: 13 - 25.

Curtin, D., and H. P. W. Rostad. 1997. Cation exchange and buffer potential of Saskatchewan soils estimated from texture, organic matter and pH. Can. J. Soil Sci. **77**: 621 - 626.

Elliott, J. A., B. M. Toth, R. J. Granger, and J. W. Pomeroy. 1998. Soil moisture storage in mature and replanted sub-humid boreal forest stands. Can. J. Soil Sci. **78**: 17 - 27.

Farrar, J. L. 1995. Trees of Canada. Fitzhenry & Whiteside and the Canadian Forest Service, Natural Resources Canada, and Canada Communications Group-Pub. Supply and Services Canada, Ottawa. 502 pp.

Frankland, J. C., J. D. Ovington, and C. Macrae. 1963. Spatial and seasonal variation in soil, litter, and ground vegetation in some Lake District woodlands. J. Ecol. **51**: 97 - 112.

Fredeen, A. L., and R. F. Sage. 1999. Temperature and humidity effects on branchlet gas-exchange in white spruce: an explanation for the increase in transpiration with branchlet temperature. Tree Struct. Funct. **14**: 161 - 168.

Fritts, H. C. 1976. Tree rings and climate. Academic Press, London. 567 pp.

Fyles, J. W., and W. B. McGill. 1987. Nitrogen mineralization in forest soil profiles from central Alberta. Can. J. For. Res. **17**: 242 - 249.

Grelle, A., A. Lindroth, and M. Molder. 1999. Seasonal variation of boreal forest surface conductance and evaporation. Agric. For. Meteorol. **98-9 Special Issue**: 563 - 578.

Grelle, A., A. Lundberg, A. Lindroth, A. S. Moren, and E. Cienciala. 1997. Evaporation components of a boreal forest: Variations during the growing season. J. Hydrol. **197**: 70 - 87.

Gross, K. L., K. S. Pregitzer, and A. J. Burton. 1995. Spatial variation in nitrogen availability in three successional plant communities. J. Ecol. **83**: 357 - 367.

Helling, C. S., G. Chesters, and R. B. Corey. 1964. Contribution of organic matter and clay to soil cation-exchange capacity as affected by pH and saturating solution. Soil Sci. Soc. Am. Proc. **28**: 517 - 520.

Hobbie, S. E. 1996. Temperature and plant species control over litter decomposition in Alaskan tundra. Ecological Monographs **66**: 503-522.

Hobbie, S. E., J. P. Schimel, S. E. Trumbore, and J. R. Randerson. 2000. Controls over carbon storage and turnover in high-latitude soils. Glob. Chang. Biol. **1**: 196-210.

Hostin, P. J., and S. J. Titus. 1996. Indirect site productivity models for white spruce in Alberta's boreal mixedwood forest. For. Chron. **72**: 73 -79.

Huang, W. Z., and J. J. Schoenau. 1997. Seasonal and spatial variations in soil nitrogen and phosphorus supply rates in a boreal aspen forest. Can. J. Soil Sci. **77**: 597 - 612.

Ike, A. F., and J. R. Clutter. 1968. The variability of forest soils of the Georgia Blue Ridge Mountains. Soil Sci. Soc. Am. Proc. **32**: 284 - 288.

Järvinen, E., T. J. Hokkanen, and T. Kuuluvainen. 1993. Spatial heterogeneity and relationships of mineral soil properties in a boreal *Pinus sylvestris* stand. Scand. J. For. Res. **8**: 435 - 445.

Keeney, D. R. 1980. Prediction of soil nitrogen availability in forest ecosystems: A literature review. For. Sci. **26**: 159 - 171.

Kimmins, J. P. 1996. Importance of soil and role of ecosystem disturbance for sustained productivity of cool temperate and boreal forests. Soil Sci. Soc. Am. J. **60**: 1643 - 1654.

Klijn, F., and J. P. M. Witte. 1999. Eco-hydrology: groundwater flow and site factors in plant ecology. Hydrogeology J. **7**: 65 - 77.

Knoepp, J. D., and W. T. Swank. 1997. Rates of nitrogen mineralization across an elevation and vegetation gradient in the southern Appalachians. Plant and Soil **204**: 235-241.

La Roi, G. H., W. L. Strong, and D. J. Pluth. 1988. Understory plant community classification as predictors of forest site quality for lodgepole pine and white spruce in west-central Alberta. Can. J. For. Res. **18**: 875 - 887.

Lowe, L. E. 1972. Aspects of chemical variability in forest humus layers under mature western hemlock - western red cedar stands. Can. J. For. Res. **2**: 487 - 489.

Macyk, T. C., S. Pawluk, and J. D. Lindsay. 1978. Relief and microclimate as related to soil properties. Can. J. Soil Sci. **58**: 421 - 438.

Metcalfe, R. A., and J. M. Buttle. 1999. Semi-distributed water balance dynamics in a small boreal forest basin. J. Hydrol. **266**: 66 - 87.

Mugasha, A. G., D. J. Pluth, and G. R. Hillman. 1993. Foliar responses of tamarack and black spruce to drainage and fertilization of a minerotrophic peatland. Can. J. For. Res. **23**: 166 - 180.

Muys, B., and P. Granval. 1997. Earthworms as bio-indicators of forest site quality. Soil Biol. Biochem. **29**: 323 - 328.

Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. Plant and Soil **80**: 321 - 335.

Nasholm, T., A. Ekblad, A. Nordin, R. Giesler, M. Hogberg, and P. Hogberg. 1998. Boreal forest plants take up organic nitrogen. Nature **6679**: 914 - 916.

Paul, E. A., and F. E. Clark. 1996. Soil microbiology and biochemistry. 2nd. Academic Press, Toronto. 340 pp.

Petersen, L. W., P. Moldrup, O. H. Jacobsen, and D. E. Rolston. 1996. Relations between specific surface area and soil physical and chemical properties. Soil Sci. **161**: 9-21.

Pojar, J. 1996. Environment and biogeography of the western boreal forest. For. Chron. **72**: 51 - 58.

Quesnel, H. J., and L. M. Lavkulich. 1980. Nutrient variability of forest floors near Port Hardy, British Columbia, Canada. Can. J. Soil Sci. **60**: 565 - 573.

Rowe, J. S. 1972. Forest regions of Canada. Canadian Forestry Service, Can. For. Serv., Publ. No. 1300. 172 pp.

Soil Science Society of America. 1998a. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 27 December, 2000. Soil Science Society of America.

Soil Science Society of America. 1998b. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 15 November, 2000. Soil Science Society of America.

St. Arnaud, R. J., and G. A. Sephton. 1972. Contribution of clay and organic matter to cation exchange capacity of chernozemic soils. Can. J. Soil Sci. **52**: 124 - 126.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics. 2nd. McGraw-Hill, New York. 633 pp.

Strong, W. L., D. J. Pluth, and G. H. La Roi. 1991. Forest understory plants as predictors of lodgepole pine and white spruce site quality in west-central Alberta. Can. J. For. Res. **21**: 1675 - 1683.

Tóth, J. 1999. Groundwater as a geologic agent: AN overviewof the causes, processes, and manifestations. Hydrogeology J. **7**: 1 - 14.

Trettin, C. C., M. Davidian, M. F. Jurgensen, and R. Lea. 1996. Organic matter decomposition following harvesting and site preparation of a forested wetland. Soil Sci. Soc. Am. J. **60**: 1994-2003.

Ulrich, B., P. Benecke, W. F. Harris, P. K. Khanna, and R. Mayer. 1981. Soil processes. *In* Dynamic principles of forest ecosystems. Reichle, D. E. Ed. Cambridge Univ. Press, London. 1981. 683 pp.

Waring, R. H., and W. H. Schlesinger. 1985. Forest ecosystem concepts and management. Academic Press, London. 340 pp.

Chapter 2

Study Area and Sampling Design

2.1 Study area

The 96 km^2 study area (centered at 54°40'N, 118°13'W, 787 m ASL) is about 70 km southeast of Grande Prairie, Alberta. It falls within the Lower Foothills Natural Sub-region (Beckingham *et al.*, 1996), and lies on the border of the Wapiti Plains and the Alberta Benchland Plateau physiographic region of the Interior Plains (Twardy and Corns, 1980). It is part of the Iosegun Plain land management unit (LMU) near the border of the Latournell Delta LMU (Figure 2-1), which is delineated primarily by physiography. The study area has rolling topography (Figure 2-2) (Agriculture Canada Expert Committee on Soil Survey, 1987), and is dominantly composed of glaciolacustrine, till and glaciofluvial materials deposited during the late Pleistocene epoch (Twardy and Corns, 1980). The underlying bedrock is the Wapiti (Upper Cretaceous) and Scollard members of the Paskapoo Formation (Paleocene and Upper Cretaceous).

The Wapiti Plains area is drained toward the northeast by several rivers; the study area lies along the Latournell River. The Latournell River originates from organic soil basins outside the study area. During dry periods, its source is largely spring melt stored in these organic soil depressions (Twardy and Corns, 1980).

2.1.1 Soils

The soils of the study area are predominantly Gray Luvisols (Twardy and Corns, 1980; Agriculture Canada Expert Committee on Soil Survey, 1987), or Haplocryalfs (Soil Survey Staff, 1998). The soils of this study conform to the specifications of the Donnelly soil group (Figure 2-3). The Donnelly soil group is derived from glaciolacustrine or lacustrotill deposits (Twardy and Corns, 1980) Lacustrotill has both glaciolacustrine and till deposit characteristics. Lacustrotill has fine textures of lacustrine material, but coarse fragments of glacial till as well. The mechanism of deposition is not clear; perhaps ice-rafting over lacustrine sediment, or glacial-ice calving into paraglacial lakes occurred (Twardy and Corns, 1980; Beckingham *et al.*, 1996).

The Donnelly soil group description includes the possible occurrence of Ah < 5 cm thick, and eluvial A-horizon(s) 5 to 20 cm thick with light gray to pale brown colour. High clay content in the Bt is present with possible evidence of weak solonetzic morphological features, *i.e.*, prismatic structure with humic staining. However, the solonetzic expression in the B-horizon appears to be insufficient to meet Bn requirements (Twardy and Corns, 1980). Soils in the Donnelly group range from imperfectly to well-drained. Significant soils (15 to 40% of the map area) of the Donnelly soil group are Orthic Gray Luvisols (O. GL) and Orthic Luvic Gleysol (O. LG) in the lower slope positions "where groundwater discharge and surface waters tend to accumulate" (Twardy and Corns, 1980).

Soil temperature class was Cold based on the estimate of mean summer soil temperature (MSST) calculated from the mean of July, August, September soil temperatures at 50 cm depth (Agriculture Canada Expert Committee on Soil Survey, 1987) using the nearest available relevant data (Macyk *et al.*, 1978).

2.1.2 Regional climate

Regional climate of the study area is continental, *i.e.*, long, cold winters and mild summers (Twardy and Corns, 1980). The climate of the Lower Foothills Natural Sub-region is characterized by a mean annual temperature of 3.0 °C, and total annual precipitation of 464 mm (Beckingham *et al.*, 1996). Grande Prairie, in boreal mixedwood Alberta, was the nearest full-time weather station to the study area (Grande Prairie A, Station Id#: 3072920, 55°11' N, 118°53' W, 666 m ASL). The Grande Prairie mean annual temperature was 1.6 °C and the total annual precipitation was 450 mm (309 mm rainfall) based on 30 years of data (Environment Canada, 1998a). There were typically 117 frost free days (Twardy and Corns, 1980), and 1321 degree-days (≥ 5 °C) between April and October compared to 1324 degree-days for the annual total (Environment Canada, 1998a).

Seasonal climate data are available for locations closer to the study area, and were used to characterize the annual trends between Grande Prairie and the study area (Environment Canada, 1998a). Economy Tower (Economy LO, Station Id#: 3072160, 54°47' N, 118°14' W, 800 m ASL) is within the study area. Smoky Tower (Smoky LO, Station Id#: 3076020, 54°24' N, 118°18' W, 1158 m ASL) is south of the study area. The year 1998 (Environment Canada, 1998b) was a slightly warmer and much drier year than average (Figure 2-4).

2.1.3 Vegetation

The study area is classified as boreal mixedwood, which is characteristic of the Lower Foothills Natural Sub-region (Beckingham *et al.*, 1996). Predominant vegetation on the top slope positions were typically white spruce (*Picea glauca* (Moench) Voss) and trembling aspen (*Populus tremuloides* Michx.) with an understory dominated by the shrub green alder (*Alnus crispa* (Ait.) Pursh), bracted honeysuckle (*Lonicera involucrata* (Richards.) Banks), and prickly rose (*Rosa acicularis* Lindl.). White spruce and black spruce (Picea mariana (Mill) BSP) dominate the bottom topographic positions, with Labrador tea (*Ledum groenlandicum* Oeder), feather moss (generally *Ptilium*, *Pleurozium* and *Hylocomium* spp.) or *Sphagnum* (Figure 2-5).

2.2 Sampling design

2.2.1 Inference space

To achieve the objectives of this study toposequences were sampled within the study area. A toposequence was defined as a consecutive series of topographic position classes (Beckingham *et al.*, 1996). Soils along a toposequence primarily differed due to landscape hydrological and biogeochemical processes. Selected toposequences met several criteria. First, visible evidence was absent for recent disturbances, such as human activity, disease, insect damage/defoliation, or fire since stand origin. Second, compositionally the forest type was to be dominantly spruce and aspen mixedwood. Third, the stands were to be uniform in age along a given toposequence indicating a single fire event for stand origin. Finally, trees along toposequences were to have full canopies, and to be near optimum rotation age. In this study a full canopy was achieved by trees and shrubs once they were using site resources to their full potential, and not competing for light resources with forbs, grasses and the moss layer.

Near-optimum rotation meant the dominant aspen trees should have the initial visible signs of decadence, and white spruce should be in a subdominant canopy position, as well as in the initial stages of co-dominance with aspen. Alberta spruce-aspen mixedwood yield tables by MacLeod and Blyth (1955) were used as a guideline to indicate optimum rotation ages for maximum volume production per year. The spruce-aspen mixedwood yield tables were based on the spruce component. Mean annual increment (MAI) and periodic annual increment (PAI) of the yield tables indicated optimum rotation age was between 90 to 130 years for all of the site-index classes (*i.e.*, excellent to poor). The optimum rotation ages according to the yield tables were conservative estimates since the white spruce (shade tolerant) in fire-origin spruce-aspen mixedwoods have experienced more competition for site resources than the aspen; the white spruce have relatively limited growth per period of time. However, the yield information is still "believed to be a reasonable approximation" (MacLeod and Blyth, 1955). The authors recognize this publication does not "provide a fully adequate solution to the problem" of using site-index in mixedwoods which are composed of species with very different silvicultural characteristics (MacLeod and Blyth, 1955). According to spruce-aspen yield tables by MacLeod and Blyth (1955) the mixedwood stands on the selected toposequences appear to be near-optimum rotation age.

2.2.2 Study sites

Three toposequences were studied (Figure 2-2): Site 1 had a south aspect and was 350 m long and elevation ranged from 765 m to 789 m above sea level (ASL) (24 m relief); Site 2 had a southeast aspect was 130 m long and its elevation ranged from 812 m to 820 m ASL (8 m relief); and Site 3 had a north aspect and was 290 m in length with the top and bottom slope elevations of 762 m and 774 m (12 m relief). The length of each toposequence includes the organic soils at the bottom of the slope.

Toposequence sites (3) were subdivided into transects, transect positions, and plots. Three nearly parallel transects were established on each toposequence site, a centre transect and two lateral ones (Figure

2-5). The distance to lateral transects varied among sites: At Site 1 ± 35 m from the centre transect, at Site 2 ± 15 m and at Site 3 ± 30 m. Sampling locations (plots) along each transect are referred to as transect positions. Transect positions were determined by change in slope angle along the center transect; *i.e.*, 1 position per slope change of ≥ 0.5 m elevation in 10 m of run. As a result the number of transect positions per toposequence site was 8, 5, and 6 on Sites 1, 2, and 3 respectively. Plots were the sample units, and were located at each transect position of all three transects per toposequence site.

Subsequent to demarcation of transect position according to rate of change in slope angle, each was assigned a slope-position category according to published slope-form criteria (Figure 2-5; Beckingham *et al.*, 1996). Lower slope position was not delineated on all toposequence sites because of overlap of adjacent plots resulting from the short distance between plot positions determined by the rate of change of slope gradient. Therefore only the crest, upper, middle and toe slope positions were used to analyze toposequence sites (Figure 2-5). In comparisons among toposequences the middle slope positions had an unbalanced sample size; Site 1 had two transect positions that met the slope-form criteria of middle slope.

Subsequent to completion of morphological soil descriptions, sampling, and laboratory analysis, but before statistical analysis, specific mineral soil horizons were aggregated into one of three horizon categories (A, B and C) based on genetic features (Agriculture Canada Expert Committee on Soil Survey, 1987). The three horizon categories were used to compare the soil properties among toposequence sites and slope positions according to common genetic features. The aggregate categories were as follows: 1) A-horizon, included all A-horizon variations (Ah, Ahe, Ae, *etc.*) occurring in a soil profile, the AB transition horizon if present, and Bm or Bf developed in the A-horizon zone of polygenetic soil profiles *e.g.*, the Bm in a Brunisolic Gray Luvisol (BR. GL), and the Bf in a Podzolic Gray Luvisol (PZ. GL); 2) B-horizon, included variations of the B-horizon (Bt_1, Bt_2, Btnj, Bg, *etc.*) occurring in the soil profile and the BC transition horizon if present; 3) C-horizon, containing all variations of the horizon *e.g.*, Ck, Cca and Cg *etc.*

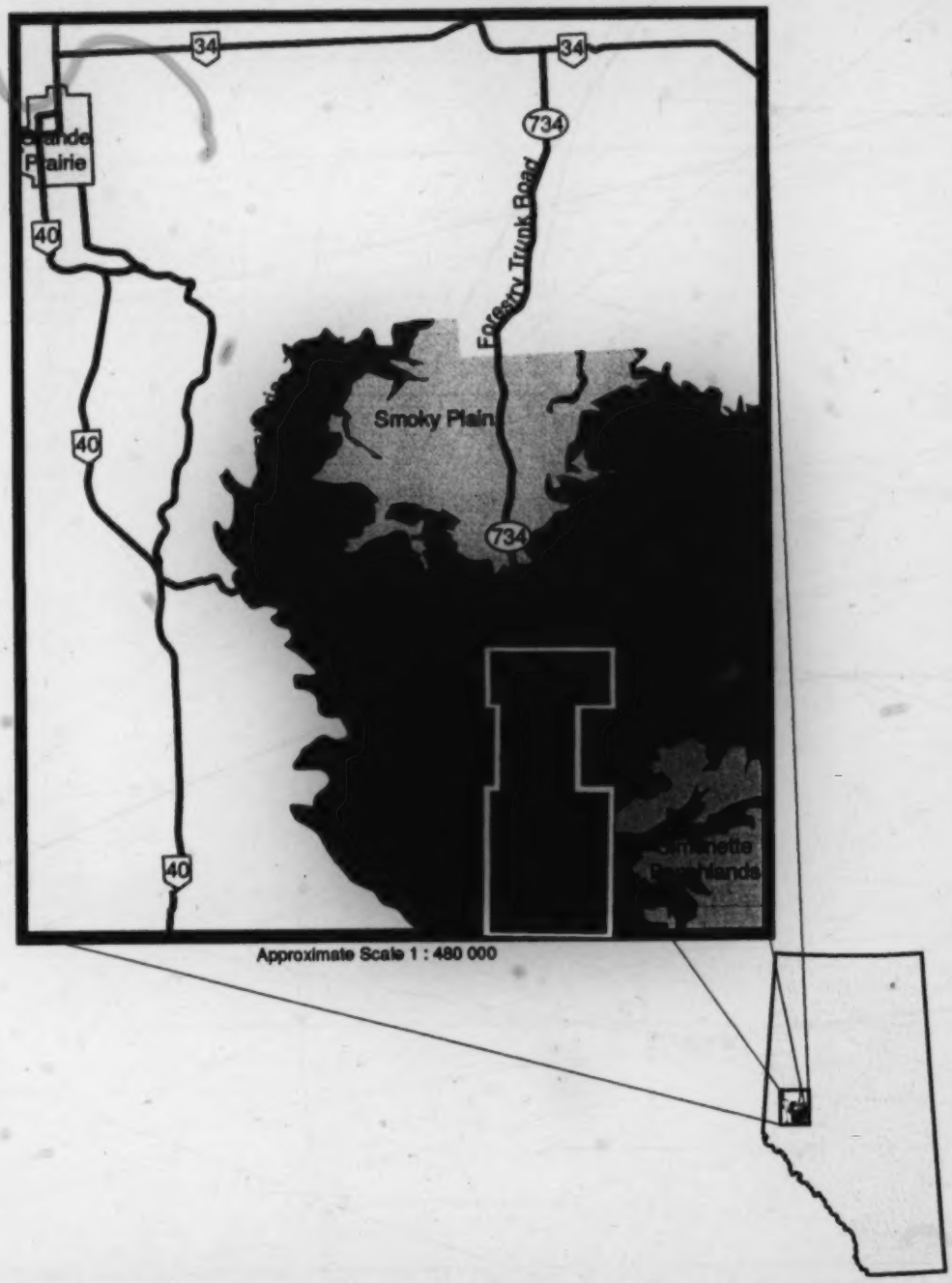

Figure 2-1. Landscape management units for the northwest section of the Canadian Forest Products Limited forest management agreement. (Adapted from Canfor. No date. Draft landscape management units: Canadian Forest Products Limited, Grande Prairie, Alberta.)

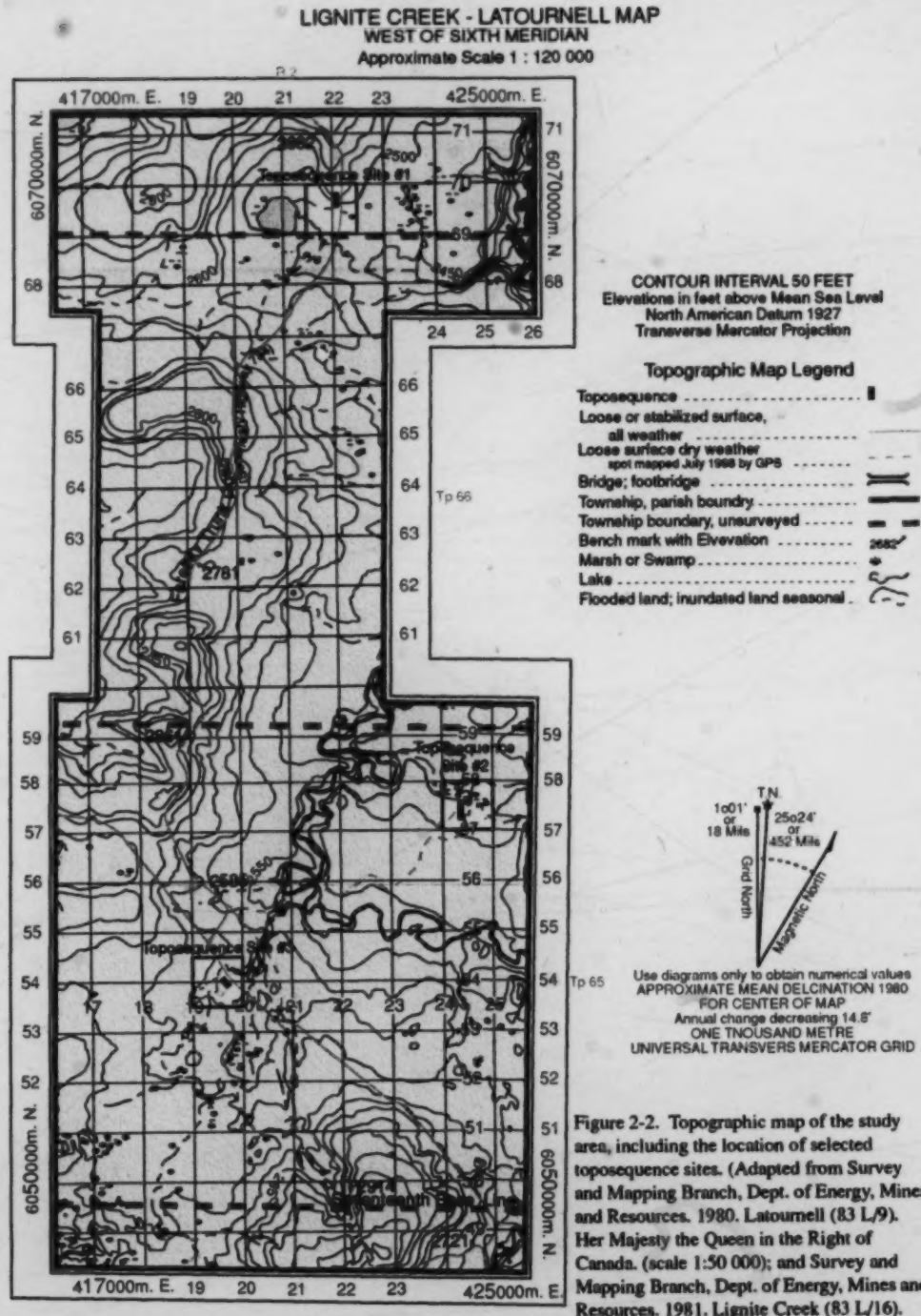

Figure 2-2. Topographic map of the study area, including the location of selected toposequence sites. (Adapted from Survey and Mapping Branch, Dept. of Energy, Mines and Resources. 1980. Latournell (83 L/9). Her Majesty the Queen in the Right of Canada. (scale 1:50 000); and Survey and Mapping Branch, Dept. of Energy, Mines and Resources. 1981. Lignite Creek (83 L/16). Her Majesty the Queen in the Right of Canada. (scale 1:50 000))

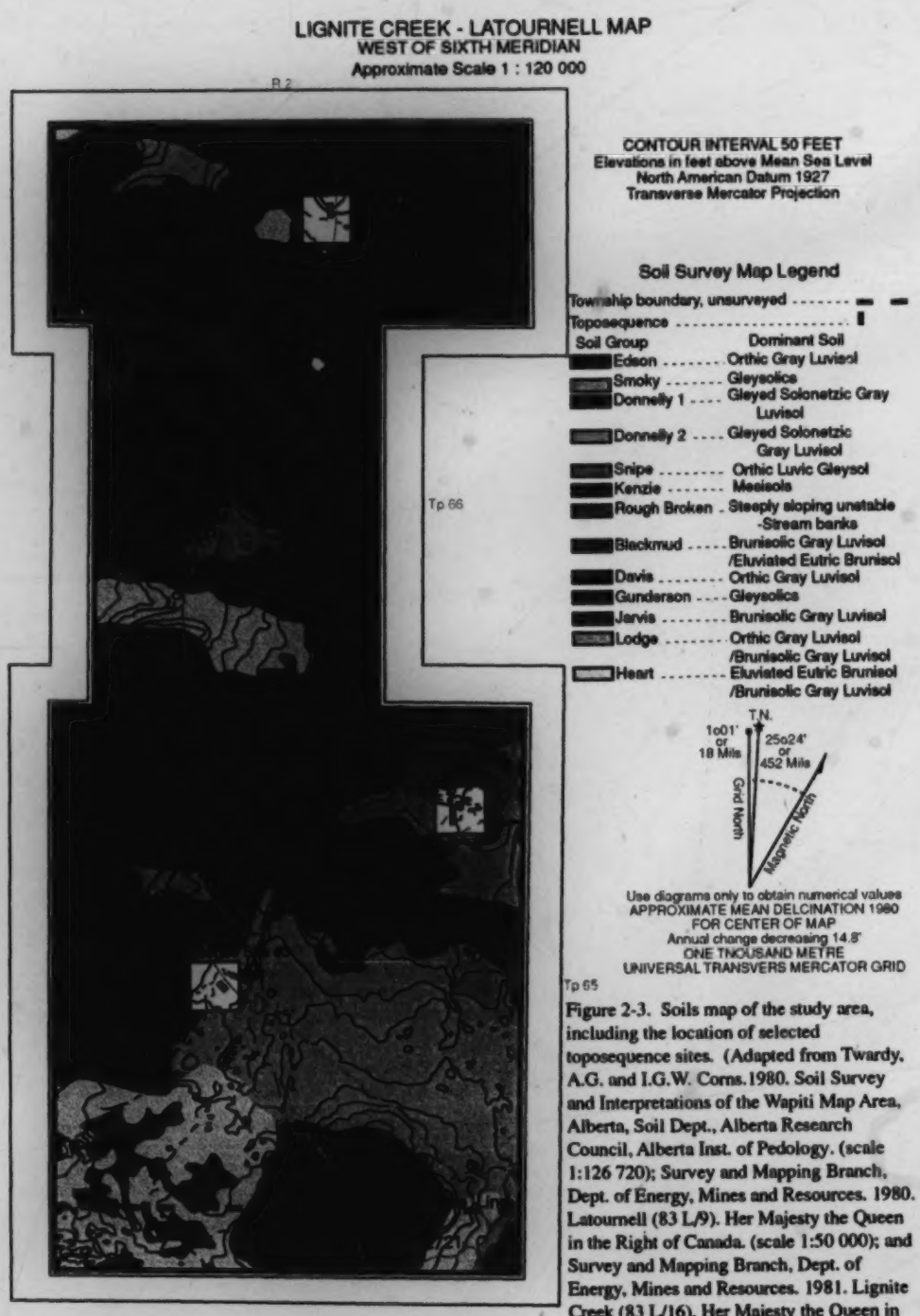

Figure 2-3. Soils map of the study area, including the location of selected toposequence sites. (Adapted from Twardy, A.G. and I.G.W. Corns.1980. Soil Survey and Interpretations of the Wapiti Map Area, Alberta, Soil Dept., Alberta Research Council, Alberta Inst. of Pedology. (scale 1:126 720); Survey and Mapping Branch, Dept. of Energy, Mines and Resources. 1980. Latournell (83 L/9). Her Majesty the Queen in the Right of Canada. (scale 1:50 000); and Survey and Mapping Branch, Dept. of Energy, Mines and Resources. 1981. Lignite Creek (83 L/16). Her Majesty the Queen in the Right of Canada. (scale 1:50 000))

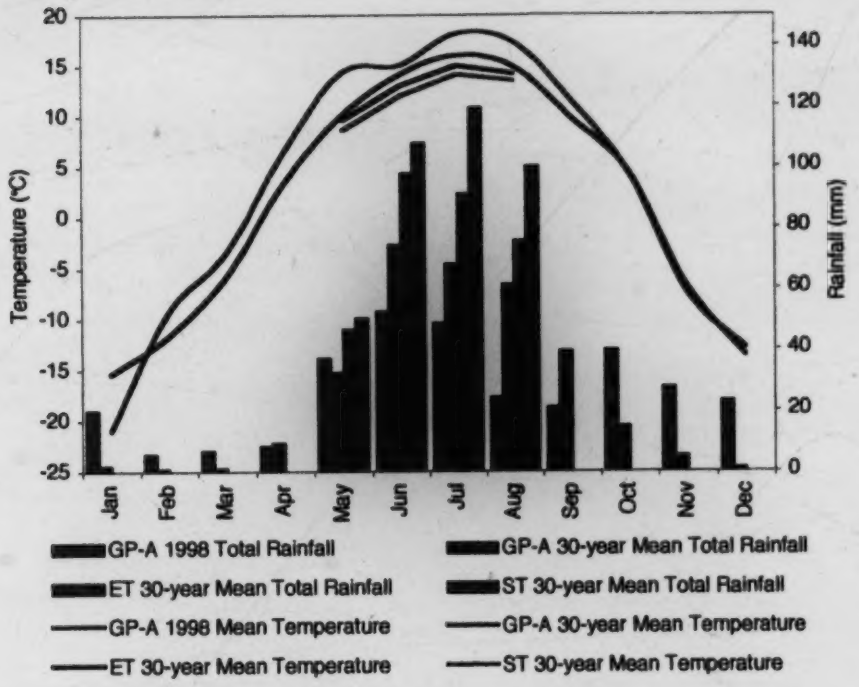

Figure 2-4. Grande Prairie Airport (GP-A; Station Id#: 3072920, 55°11' N, 118°53' W, 666 m ASL) 1998 temperature and precipitation data (pink), and the temperature and precipitation climate normals from 1961 to 1990 for the Grande Prairie Airport (green); Economy Tower (ET; blue; Station Id#: 3072160, 54°47' N, 118°14' W, 800 m ASL) and Smoky Tower (ST; brown; Station Id#: 3076020, 54°24' N, 118°18' W, 1158 m ASL).

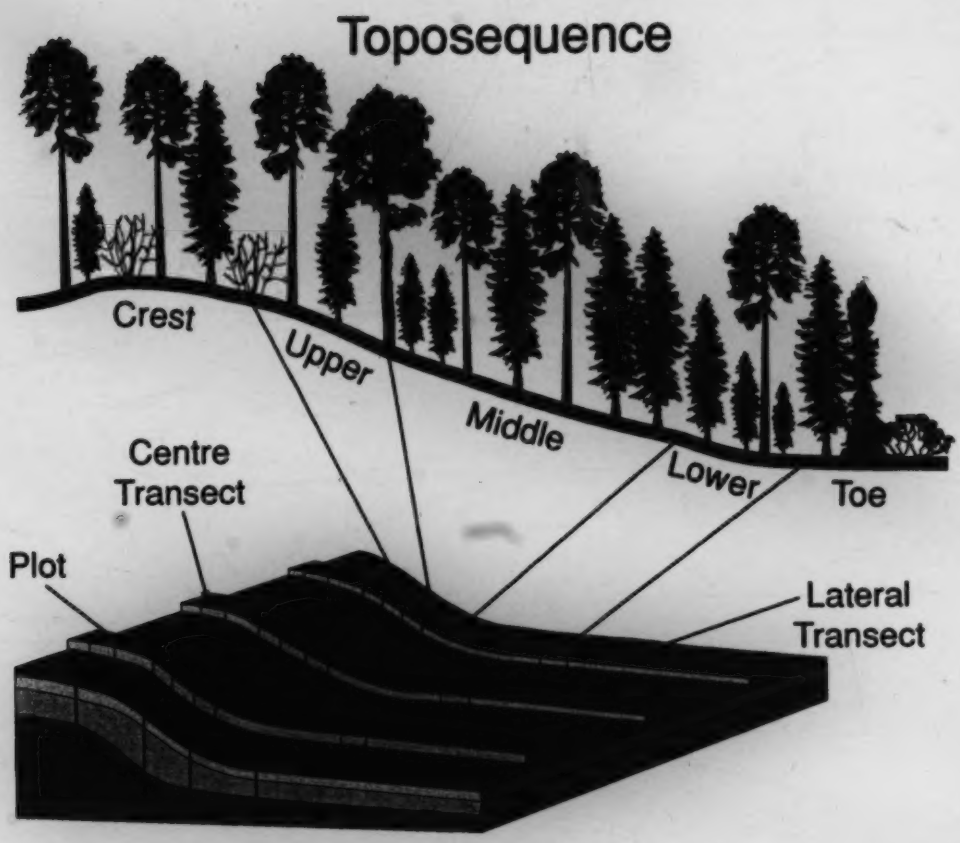

Figure 2-5. Schematic depiction of the sampling design for a toposequence site. The slope classes according to landscape form and vegetation sequence for the mixedwood stands are also shown. Slope positions were defined by landform shape (Beckingham *et al.*, 1996): the **crest** was at the top of the hill and was convex in all directions (no specific aspect); the **upper** slope was immediately below the crest, was convex but not in all directions, and had a specific aspect; the **middle** slope was planar, *i.e.*, not concave or convex, with a specific aspect; the **lower** slope was at the base of a slope and was concave with a specific aspect; the **toe** was immediately below the lower slope and was indicated by an abrupt decrease in slope angle compared to the lower slope angle. These slope-form categories apply to toposequences with less than 300 m relief.

2.3 Literature cited

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. Res. Br. Agric. Canada, Minister of Supply and Services Canada, Ottawa. Publ. No. 1646. 164 pp.

Beckingham, J. D., I. G. W. Corns, and J. H. Archibald. 1996. Field guide to ecosites of west-central Alberta. Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent., Edmonton. Special Rept. 9.

Environment Canada. 1998a. Canadian Climate Normals 1961 to 1990. www.cmc.ec.gc.ca/climate/normals/E_AL_NDX.HTM. Accessed: 15 November, 2000. Environment Canada.

Environment Canada. 1998b. Grande Prairie Airport (Station Id#: 3072920) 1998 Weather Data. Environment Canada, Ottawa, Email & Attachments, Thursday, November 23, 2000, 8:00 AM.

MacLeod, W. K., and A. W. Blyth. 1955. Yield of even-aged fully stocked spruce-poplar stands in northern Alberta. Dept. of For. Res., For. Res. Branch, Ottawa. Tech. Note No. 18. 34 pp.

Macyk, T. C., S. Pawluk, and J. D. Lindsay. 1978. Relief and microclimate as related to soil properties. Can. J. Soil Sci. **58**: 421 - 438.

Soil Survey Staff. 1998. Keys to soil taxonomy. 8th. U.S. Dept. of Agric., Nat. Resour. Conserv. Serv., Washington, D.C. 326 pp.

Twardy, A. G., and I. G. W. Corns. 1980. Soil survey and interpretations of the Wapiti map area, Alberta. Alberta Res. Coun., Edmonton, Alberta, 134 pp.

Chapter 3

Distribution of Soil Morphological and Texture - Associated Properties along Toposequences of White Spruce - Aspen (*Picea glauca – Populus tremuloides*) Mixedwood Communities in West-Central Alberta

3.1 Introduction

Forest productivity in the past has been strongly associated with elemental cycling in both deciduous and coniferous forests (MacDonald, 1995). Forest productivity is the "capacity of a forest to produce specific products (*i.e.*, biomass, lumber) over time" (Soil Science Society of America, 1998). This study is meant to define the physical landscape distribution of the medium in which cycling and uptake of forest plant nutrients occur in order to further explain the relationship between forest soil properties and forest productivity. Soil properties can be used to quantify the availability of air and water, and the ability of soil to retain and release nutrient ions, which are factors in plant growth. Of course, soil properties in genetic horizons are a result of soil forming factors that vary locally with topography and depth within unconsolidated geologic materials.

In this study, the soil forming factor: topography, is the primary interest with respect to the variation it causes in soil properties, and subsequently in the quality of the soil for tree growth. In small areas, such as a forest stand, the effects of regional climate and parent geological materials are common, so topography in the boreal forest has a dominant influence on soil processes. The main effect of topography is variation of soil water content and drainage, which influence site microclimate. In general, soils of upper slopes are better drained than soils of lower positions, and drainage affects biological, geological and chemical processes. These processes influence the soil properties and effective depth (or volume) of soil, the "portion of soil that is either occupied or capable of being occupied by the roots of the tree" (Barnes *et al.*, 1998). In previous studies depth has been shown to have a role in tree growth (Carmean, 1975).

Soil properties may provide an indication of site productivity because they describe the medium in which plants grow. The aim of this study is to answer the questions:

1. What is the depth of forest floor and mineral soil horizons along toposequences of mixedwood stands in west-central Alberta;
2. How are potentially important soil properties distributed along toposequences; and
3. How is forest productivity related to these soil properties?

3.2 Materials and methods

3.2.1 Study area

The study area (54°40'N, 118°13'W, 787 ± 26 m ASL) was approximately 70 km southeast of Grande Prairie, Alberta. It falls within the Lower Foothills Natural Sub-region (Beckingham *et al.*, 1996), and lies on the border of the Wapiti Plains and the Alberta Benchland Plateau physiographic regions of the Interior Plains (Twardy and Corns, 1980). This area has rolling relief (Agriculture Canada Expert Committee on Soil Survey, 1987), and is comprised of glaciolacustrine, till and glaciofluvial materials deposited during the late Pleistocene epoch (Twardy and Corns, 1980).

The soils typical of the study area are Gray Luvisols (Twardy and Corns, 1980; Agriculture Canada Expert Committee on Soil Survey, 1987), or Haplocryalfs (Soil Survey Staff, 1998). The soils of this study conform to the specifications of the Donnelly soil group. The Donnelly soil group is derived from glaciolacustrine or lacustrotill deposits (Twardy and Corns, 1980). The Donnelly soil group includes Orthic Gray Luvisols (O. GL) and Orthic Luvic Gleysols (O. LG) in the lower slope positions "where groundwater discharge and surface waters tend to accumulate" (Twardy and Corns, 1980).

Regional climate of the study area is continental, *i.e.*, long, cold winters and mild summers (Twardy and Corns, 1980). The climate of the Lower Foothills Natural Sub-region is characterized by a mean annual temperature of 3.0 °C, and total annual precipitation of 464 mm (Beckingham *et al.*, 1996). Grande Prairie, Alberta is the nearest full-time weather station to the study area (Grande Prairie A, Station Id#: 3072920, 55°11' N, 118°53' W, 666 m ASL). Mean annual temperature for Grande Prairie is 1.6 °C and the total annual precipitation is 450.2 mm (308.6 mm rainfall) based on 30 years of data (Environment Canada, 1998).

The study area is classified as boreal mixedwood, which is characteristic of the Lower Foothills Natural Sub-region (Beckingham *et al.*, 1996). Predominant vegetation on the upper slopes is typically white spruce (*Picea glauca* (Moench) Voss) and trembling aspen (*Populus tremuloides* Michx.) with an understory dominated by the shrubs green alder (*Alnus crispa* (Ait.) Pursh) and bracted honeysuckle (*Lonicera involucrata* (Richards.) Banks). Toe slope positions are dominantly white spruce and black spruce (*Picea mariana* (Mill.) BSP) with Labrador tea (*Ledum groenlandicum* Oeder), feather moss (generally *Ptilium*, *Pleurozium* and *Hylocomium* spp.) or *Sphagnum* ground cover.

3.2.2 Sampling design

To achieve the objective of this study prospective toposequences were sampled within the study area. A toposequence was defined as a consecutive series of topographic positions (Beckingham *et al.*, 1996). Toposequences were selected to meet several criteria. First, they were examined to ensure there were no recent disturbances, such as human activity, disease, insect damage/defoliation, or fire since stand origin. Second, the forest was to be dominantly spruce and aspen mixedwood. Third, the stands were to be

uniform in age along a given toposequence. Finally, trees along toposequences should not be degrading as a result of old age, but near to the optimum rotation age with a full canopy.

Three toposequences were used as study sites: Site 1 was 350 m long and varied between 765 m and 789 m above sea level (ASL) (24 m relief). Site 2 was 130 m long and its elevation varied from 812 m to 820 m ASL (8 m relief). Site 3 was 290 m, and the elevations of the top and bottom of the slope were 762 m to 774 m (12 m relief).

Toposequence sites were subdivided into transects (3), transect positions, and plots (Figure 2-5). Three nearly parallel transects separated by 15 m to 30m were established for replicated sampling of slope position within a toposequence site. Plots were the sampling locations along each transect within a toposequence site. In the terrain of this study, the lower slope position was not sampled on toposequence sites as a result of the close proximity of adjacent plots. Therefore, only the crest, upper, middle, and toe slope positions were used to compare toposequence sites. In all comparisons, the middle slope positions had an unbalanced sample size because Site 1 had two transect positions that met the form criteria of middle slope.

Also, following completion of soil morphological description and sampling, the specific mineral soil horizons were aggregated into one of three horizon categories based on genetic features (Agriculture Canada Expert Committee on Soil Survey, 1987). The aggregate categories were as follows: 1) A-horizon, including all A-horizon variations (Ah, Ahe Ae, *etc.*) occurring in a soil profile, the AB transition horizon if present, and Bm or Bf developed in the A-horizon zone of polygenetic soil profiles, *e.g.*, the Bm in a Brunisolic Gray Luvisol (BR. GL), and the Bf in a Podzolic Gray Luvisol (PZ. GL); 2) B-horizon including variations of the B-horizon (Bt_1, Bt_2, Btnj, Bg, *etc.*) occurring in the soil profile and the BA and BC transitional horizons if present; 3) C-horizon, containing all variations of the C-horizon *e.g.*, Ck, Cca and Cg *etc.*

3.2.3 Ecological response variables of forest mixedwood communities

Stand data were collected from plots (sites). Stand-level variables such as effective leaf area index[1] (LAI), basal area (BA), tree density and age were used to assess similarity of toposequence sites. Basal area, mean annual increment of BA and LAI were also used as estimates of net primary productivity 1.3 m above the forest floor.

Net primary productivity is a fundamental measure of site productivity (Soil Science Society of America, 1998). It is the rate of plant (autotrophic) biomass (*i.e.*, C assimilated) accumulation after losses due to consumption and respiration. Productivity is the rate of accumulation of a specified material

[1] Effective leaf area index (LAI) value as measured by the Li-Cor 2000 Plant Canopy Analyzer (Gower and Norman, 1991; Chen, 1996; Hall, 1998b; Li-Cor Inc., n.d.). It may be abbreviated eLAI, LAI_e, or L_e in other literature.

(Kimmins, 1987), and in this study it refers more specifically to tree and shrub net biomass by excluding biomass under 1.3 m height (breast height). Effective leaf area index, basal area, and basal area increment will be referred to as ecological response variables because they are surrogates for net primary production in response to site conditions.

Leaf area index as a proxy of the site net primary productivity, was measured by a LAI-2000 Plant Canopy Analyzer (Li-Cor Inc., n.d.). Within plot measurements were taken from nine locations (8 at every 45° azimuth along the plot perimeter plus one at plot center) to estimate effective LAI per 100 m^2 square plot. Measurements were only taken when continuous and uniform cloud cover occurred during the period from 25 to 31 August 1998 between 8 AM and 4 PM, immediately prior to the first evidence of leaf abscission. Continuous and uniform cloud cover during the day provided uniform light conditions for measurements. Light intensity readings required about 10 min per plot: about four minutes for diffuse light (Q_i) within plot (n=9), and about six minutes to traverse between the plot and an area with no overhead cover (Q_o).

Leaf area index was adjusted by basal area (LAI adj. BA) for species composition (*i.e.*, proportion of coniferous component) of the sample site (plot). The adjustment was necessary since the Li-Cor LAI-2000 instrument underestimates LAI by 35 to 40% (Gower and Norman, 1991). Therefore, LAI was corrected for the proportion of conifer species using the following equation (eq. 3-1):

[3-1] LAI adj. BA = LAI ((BA *deciduous*/BA *total*) x 1.0) + LAI ((BA *coniferous*/BA *total*) x 1.4)

Where, BA is the basal area and 1.4 is the correction factor for the underestimation of the conifer component (Gower and Norman, 1991; Hall, 1998a; Hall, 1998b).

The forest stand parameters of basal area, tree height, tree diameter outside bark (dbhob), sapwood area, and age at 1.3 m above ground level (breast height) were collected from sample trees selected by the point sample method (Husch *et al.*, 1982) from plot centers. These data sets were collected between 27 August and 14 September 1998. Only plot centers nearest to the midpoints of the crest, lower, and toe positions of the slope were sampled to prevent repeated measurement of large sample trees from adjacent within-transect positions. Tree age was estimated from tree cores extracted at 1.3 m and stored at –9 °C until growth-ring analysis.

3.2.4 Soil properties

Soils in this study were characterized by a pedon description and composite horizon samples at each plot along the center transect. The spatial sampling intensity varied by horizon depth according to the general knowledge of horizontal and vertical spatial variability of soil properties (Metz *et al.*, 1966; Cameron *et al.*, 1971; Amponsah, 1998). The numbers of locations sampled were forest floor and A-

horizon – three per plot, B-horizon – one per plot, and C-horizon – one per center-transect plot. Forest floor and A-horizon thickness were measured while collecting inorganic N samples. Thickness of lower mineral soil horizons, (B- and C-horizons) was only measured during the morphological description of the center-transect soil profiles.

Bulk density of the forest floor was sampled by systematically removing 900 cm^2 and measuring undisturbed horizon thickness to the nearest 0.5 cm. Mineral soil bulk density was sampled by Uhland corer (*ca* 331 cm^3). Mineral soil samples, of known *in situ* volume, were dried at 105°C (Culley, 1993) to constant weight. Organic horizon material (L, F, and H) was dried at 75°C to constant weight.

Results from particle size analysis were used for the estimation of field capacity, permanent wilting point and cation exchange capacity. Particle size distribution was determined using the hydrometer method (Sheldrick and Wang, 1993). The hydrometer was used to estimate the particle size distribution by measuring suspension density at intervals while particles were settling according to their mass. Soil samples were prepared for analysis by breaking soil aggregates with a wooden rolling pin, to pass through a 2 mm sieve to remove coarse fragments. The <2 mm fraction was dispersed in sodium hexametaphosphate (50 g L^{-1}) for 20 hours. Variations from the procedure described by Sheldrick and Wang (1993) included taking the preliminary hydrometer reading at 30 seconds and the second reading at 60 seconds after settling was allowed to begin. Then Stoke's Law (Day, 1965; Craig, 1983; Marshall *et al.*, 1996) was used to calculate the diameter of particles in suspension at 3 to 6 hours and 18 to 24 hours instead of measuring suspended particles at a specific time (Day, 1965). Stoke's Law relates particle size (radius) and terminal settling velocity, which can be used to estimate settling time of particles over a given distance. The moist weight of each particle size analysis sample was corrected to oven-dried weight, using subsamples for water content determination.

Field capacity and permanent wilting point were estimated from the relationship between particle size distribution and matric potentials (Ψm). Field capacity (Ψm @ -33 kPa) and permanent wilting point (Ψm @ -1500 kPa) are strongly related to the clay-size fraction because clay has a dominant role in determination of soil surface area (Petersen *et al.*, 1996). The quantity of small-size soil particles greatly affects the amount of surface area in soil that is available for water adsorption and capillarity (matric forces). Matric forces dominate in unsaturated soils especially those near -1500 kPa (Petersen *et al.*, 1996).

Results from particle size analysis and water desorption measurements (water content, θ, at specific Ψm) were taken from Verma (1968) for soils near Edmonton. Multiple linear regression analysis (McClave and Dietrich II, 1991; Johnson and Bhattacharyya, 1992; Ryan, 1997) was used to construct the mathematical relationships between soil water content (θ) at -33 kPa and -1500 kPa, and the < 50 μm soil particle fraction. Only results from horizons with organic matter <2 g $100g^{-1}$ (0.012 g organic-C (g soil)$^{-1}$; assuming that the organic matter contains 58g C $100g^{-1}$ soil, *i.e.*, the Van Bemmelen factor (Kalra and Maynard, 1991)) were used to develop these equations, since mineral soil horizons of Gray Luvisolic soils

generally contain low concentrations of soil organic matter. Analysis of the data found that clay and silt content (by mass) were influential in the prediction models for soil water content at both matric potentials. Estimation equations for soil water content at -33 kPa (eq. 3-2) and -1500 kPa (eq. 3-3) that resulted from the regression analyses had n = 211, and R^2-values of 0.818 and 0.895, and MSEs of 20.952 and 3.470 (g $100g^{-1})^2$ respectively.

[3-2] θm (Ψm @ -33 kPa), g $100g^{-1}$ = 1.883 + 0.266(*Silt*, g $100g^{-1}$) + 0.466(*Clay*, g $100g^{-1}$)

[3-3] θm (Ψm @ -1500 kPa), g $100g^{-1}$ = 0.460 + 0.067(*Silt*, g $100g^{-1}$) + 0.304(*Clay*, g $100g^{-1}$)

Cation exchange capacity was also estimated from regression of CEC on soil particle size. Cation exchange capacity of a soil horizon is influenced by the surface area imparted by soil colloids and their surface charge densities. When soil organic matter concentration is low, the soil surface area is associated primarily with the <2 μm particle fraction. Surface charge density varies with clay mineralogy. Furthermore, surface charge density may vary with ambient pH, *i.e.*, pH-dependent charge. Therefore, soil organic matter content and clay mineralogy are two concerns in estimation of cation exchange capacity (Helling *et al.*, 1964; St. Arnaud and Sephton, 1972; Petersen *et al.*, 1996; Curtin and Rostad, 1997).

The local clay mineralogical composition has an effect on cation exchange capacity due to the atomic structure of some clay types and the penetration of water into the crystalline structure which causes swelling (interlayer expansion) and therefore increases accessibility to clay-particle surface area. Smectite and vermiculite are examples of expanding 2:1 mineral types (Brady, 1990). Clay types with internal surfaces may have total surface areas of more than 800 m^2 g^{-1} (Brady, 1990; Petersen *et al.*, 1996) compared to 10 m^2 g^{-1} of clays with only external surfaces (Brady, 1990). Since existing models in the literature (Helling *et al.*, 1964; St. Arnaud and Sephton, 1972; Curtin and Rostad, 1997) were from areas of different clay type composition (Kodama, 1979), a regional model for this study was developed. The regional model developed for cation exchange capacity (eq. 3-4) was based on particle size and cation exchange capacity data from selected horizons of all of the Wapiti area soil units described in Twardy and Corns (1980), 'Appendix A'. The only criterion applied in the selection of horizons from the Wapiti area soil units described by Twardy and Corns (1980) was an organic matter content of <2 g $100g^{-1}$; Two-thirds of the soil units selected were classified as Luvisols.

Stratification of clay mineralogical types by horizon was considered by examining the CEC (cmol(+) kg^{-1})/clay ratio (g $100g^{-1}$). The primary concern was stratification of clay mineral types due to preferential illuviation of fine clays (< 0.2 μm) in Luvisolic soils. The CEC/clay ratios were 0.92 ± 0.11 and 0.65 ± 0.02 (mean ± SE) for the A- and B- horizons respectively. There was evidence (p = 0.018) that the mean CEC/clay ratios of the A- and B-horizons were different. However, the lack of difference at the 99% confidence level between CEC/clay ratio of the A- and B-horizons suggests that preferential eluviation of

clay mineralogical types may be occurring, but a single model for both A- and B-horizons would be acceptable for application in this study.

Organic matter content is the second concern for estimation of cation exchange capacity. Soil organic matter of Gray Luvisols is generally low so that only soil horizons with <0.02 g g^{-1} or 0.0120 g organic-C g^{-1} soil (*i.e.*, according to the Van Bemmelen factor (Kalra and Maynard, 1991)) were used in regression analysis. The cation exchange capacity equation (eq. 3-4) developed had n = 65, an R^2-value of 0.845, and MSE of 4.310 (cmol(+) kg^{-1})^2.

[3-4] $$\text{CEC, cmol(+) kg}^{-1}\text{ at pH 7} = 2.464 + 0.463(\textit{Clay}, \text{ g 100g}^{-1})$$

The method of determining soil pH in distilled water (pHw) is described in Kalra and Maynard (1991). Mineral soil-to-water (by mass) ratio was 1:2 and forest floor-to-water ratio was 1:12. Non-incubated forest floor samples collected from 29 to 31 July were used to determine pHw. These samples were frozen (-9 °C) in field moist condition and thawed once, for a brief period so a sub-sample could be drawn to determine ammonium, nitrate and pHw. Samples of mineral horizons were cooled and stored at approximately 3 °C in SC Johnson large heavy duty Ziploc® freezer bags until pH was determined.

3.2.5 Statistical analyses

Analysis of variance (McClave and Dietrich II, 1991; Johnson and Bhattacharyya, 1992) was performed using SPSS 6.1.1 (SPSS, 1995). Two-way analysis of variance (two-way ANOVA) was used on ecological response and soil property variables to determine differences among toposequence sites (eq. 3-5). The null hypothesis was that toposequence sites were not different. Two-way ANOVA was also used to test the difference between slope positions. The null hypothesis was that there was no difference among slope positions for soil properties.

[3-5] $$Y_{ijk} = \mu + T_i + S_j + TS_{ij} + \varepsilon_{(ij)k}$$

where Y_{ijk} is the response for the *k*th plot within *j*th slope position within *i*th toposequence site, μ is the grand mean, T_i is the fixed effect of the *i*th toposequence site, and S_j is the fixed effect of the *j*th slope position (crest, upper, middle or toe). The TS_{ij} term is the fixed effect of the interaction between the *i*th toposequence site and the *j*th slope position, and $\varepsilon_{(ij)k}$ is the fixed effect of the *k*th plot within the *j*th slope position within the *i*th toposequence site. The assumptions for the analysis of variance were that the experimental errors are random, normally and independently distributed with a zero mean and common variance (Steel and Torrie, 1980; McClave and Dietrich II, 1991).

Microsoft Excel 98 was used to perform t-tests, assuming unequal variance, and to generate Pearson correlation matrices (Microsoft, 1998). The t-tests with the assumption of unequal variance were used because of the variance trend; variances increased from crest slope position to toe slope position. The t-tests identified differences among slope positions detected by ANOVA. Analyzing toposequence sites independently was not necessary because they were generally similar in ecological response variables and individual soil properties, according to two-way ANOVA. Therefore, the comparison of slope positions was accomplished by using all the toposequences together, and gave 9 observations per crest, upper and toe positions and 12 observations per middle slope position.

3.3 Results

3.3.1 Toposequence sites

The toposequence sites vary in slope aspect and length, but elevations are similar (Table 3-1). Stand and soil attributes are similar among the three toposequence sites (Table 3-2).

For toposequence sites, the maximum tree age of *Populus* spp. (mostly *P. tremuloides*) was used to estimate the time since the last presumed stand-originating fire (Table 3-2). Maximum mean time elapsed since the last stand originating fire is 92 ± 12 years. Maximum deciduous ages occurred in the crest, upper and middle slope positions on all toposequences. The difference in maximum ages, *i.e.*, deciduous age minus coniferous age was 16, 15 and -14 years for sites 1, 2, and 3 respectively. The older coniferous age at Site 3 may indicate a residual tree (*Picea mariana*) that survived the stand-originating fire, as the maximum tree age occurred at the lowest slope position of a north facing aspect.

Boreal stands in which no single species exceeds 80% of the BA is considered mixedwood (MacDonald, 1995). Percent stand composition was calculated from toposequence BA, and all three toposequences qualify as boreal mixedwood stands by this criterion (Table 3-2). Mean conifer species compositions, by BA, for all toposequences by slope position were 30, 36, 42 and 79% for crest, upper, middle, and toe positions respectively. Deciduous species included trembling aspen and coniferous trees were typically white spruce. Sub-dominant tree species were typically balsam poplar (*Populus balsamifera* L.) and black spruce (*Picea mariana* (Mill.) BSP).

For the comparison of toposequence sites a two-way ANOVA was used (eq. 3-5). Leaf area index was the only ecological response variable that had a significant interaction of site and slope position (Table 3-3). The LAI interaction ($p = 0.002$) was expressed as 2.90 ± 0.39 m^2 m^{-2} at the toe of the slope of Site 3, which was much lower than the same slope positions of Site 1 (3.87 ± 0.39) and Site 2 (3.69 ± 0.35). The main effect of site LAI ($p = 0.02$) was less detectable than the interaction, and was caused by a difference in LAI of nearly 0.5 m^2 m^{-2} between Site 1, and Sites 2 and 3. Figure 3-1 (a,b,c,d) shows mean LAI among sites by slope positions. The mean basal area of Site 3 was about 11 m^2 ha^{-1} less than that of Sites 1 and 2, differences were detectable only by the two-way ANOVA ($p = 0.01$).

Selected soil properties of horizon thickness, bulk density, particle size distribution, estimated available water capacity, available water content, estimated cation exchange capacity, and soil pHw were examined to determine differences among toposequence sites. Using the two-way ANOVA there was no difference ($p > 0.05$) in forest floor thickness among sites, but in the A-horizon there was a difference (Table 3-4). For forest floor and A-horizon, bulk density differed ($p \leq 0.05$) among sites (Table 3-4). In the A- and B-horizons, differences ($p \leq 0.05$) were detected among sites for the sand and clay-size fractions (Table 3-4). A-horizon silt content was also different ($p = 0.003$) among sites.

Soil water content sampled during late-July (29th to 31st) and mid-August (12th to 15th) 1998 showed evidence ($p \leq 0.05$) of differences among sites in the forest floor, and there was also a difference in the A-horizon during late-July (Table 3-4). However, there was no difference among sites in the A- and B-horizons during early-October (7th to 13th). Particle size analysis results were used to estimate water content (by mass) at -33 (field capacity) and -1500 (permanent wilting point) kPa matric potentials. The difference between soil water at -33 and -1500 kPa was used to estimate available water capacity (by volume, since bulk density and horizon thickness were measured) to test for difference among toposequence sites. Differences ($p \leq 0.05$) were detected in both A- and B-horizons in all slope positions (Table 3-4). Cation exchange capacity of the sites was also estimated using particle size analysis results. Difference ($p \leq 0.05$) was detected for CEC (cmol(+) kg^{-1}) among sites in the A- and B-horizons (Table 3-4). For soil pHw, forest floor and A-horizon were different ($p \leq 0.05$) among sites, but in the B-horizon no difference was detected (Table 3-4).

For each soil property examined, many of the differences detected among toposequences were not very strong, with p-values ≥ 0.001, nor was there consistent difference among sites by soil horizons. This suggests that toposequence sites were not completely different from one another. In addition several examined soil variables indicated there was similarity ($p \geq 0.05$) among toposequence sites. Ecological response variables also showed relatively weak and inconsistent differences among sites.

3.3.2 Slope position

For the ecological response variables examined, only LAI was different among slope positions (Table 3-5). The LAI value of the toe slope position was significantly greater than the upslope positions.

Difference among slope positions was also tested using soil properties. The difference among slope positions was tested using two-way ANOVA's (eq. 3-5). The two-way ANOVA model was used to separate any marginal effect of toposequence site from the residual term used in the denominator of F-ratio to test slope position. The objective was to increase detection sensitivity for variation largely caused by the effect of slope position (Steel and Torrie, 1980; Brown, 1994).

The two-way ANOVA model indicated forest floor thickness was greater ($p \leq 0.05$) at the toe of the slope (average 9 cm) compared to the crest, upper and middle positions (Table 3-6). The A-horizon

thickness at the crest was greater than the upper, middle and toe positions. No change in B-horizon thickness was observed along the toposequence.

Bulk densities were not different ($p > 0.05$) in the forest floor, A-and B-horizon according to the two-way ANOVA tests (Table 3-7). Forest floor bulk density was very similar all along the toposequence: 0.09 ± 0.01 g cm^{-3} (mean ± SE). In the mineral soil, bulk density ranged from 1.13 ± 0.02 g cm^{-3} in the A-horizon to 1.63 ± 0.11 g cm^{-3} in the C-horizon. The average bulk density change between A- and B-horizon was 1.17 ± 0.09 to 1.52 ± 0.10 g cm^{-3}, and it usually occurred between an abrupt (< 2 cm) or clear (2 to 5 cm) boundary. The rapid change in bulk density between the A- and B-horizons corresponds to the major change in particle size distribution (Table 3-8), which indicates the eluvial A-horizon is dominantly silt-loam and the illuvial B-horizon mainly clay at each slope position. Descriptive root distributions show the greatest abundance of roots of all size classes occurred in the forest floor and A-horizons (Figure 3-5).

Difference in particle size distribution among slope positions was detected in the A- and B-horizon. The clay-size fraction in the A-horizon was greatest at the toe compared to the crest, upper and middle slope positions (Table 3-8). No difference in the clay-size fraction was detected ($p > 0.05$) in the B-horizon. The silt content was lowest in the middle slope A-horizon compared to other slope positions in the A-horizon. In the B-horizon silt content was greatest ($p \leq 0.05$) in the toe.

Volumetric water content in the forest floor increased from crest to toe (Figure 3-2 a) during late-July and mid-August 1998. In both periods, the forest floor water content in the crest, upper and middle slope positions were similar at about 4 mm ($p \leq 0.05$). In the mineral soil horizons during early-October, when soil water contents were sampled again, there was no difference among slope positions (Figure 3-2 b,c,d).

Estimated volumetric water content at -33 kPa was different only in the A-horizon between the crest and upper, and crest and middle slope positions (Figure 3-2 b). The average soil water content of the A-horizon exceeded the water content at -33 kPa at the middle slope in early-October, and may be the result of a wetting front caused by precipitation during the period of sampling. In addition, the A-horizon texture (loam) at the middle slope position was more coarse than the texture found at other slope positions (mostly silt-loam). Water content at -1500 kPa in the A-horizon at the crest was about 25 mm, and was significantly greater ($p \leq 0.05$) than the upper and middle slope positions by nearly 10 mm. No differences were detected for the water content at -33 or -1500 kPa in the B- and C-horizons. Available water content did not reach below -1500 kPa at any slope position or horizon (Figure 3-2 b,d), although in the B-horizon it was only 3 to 5 mm greater at the upper and middle slope positions (Figure 3-2 c). Available water capacity to a depth of 1.20 m was greatest at the upper slope position and lowest in the middle slope; the general trend along the entire toposequence decreased from crest to toe (Figure 3-3). Available soil water content of the soil profiles in early-October increased dramatically at the toe despite the opposite trend in profile available water capacity.

Estimated CEC in the A-horizon was 9.4 ± 0.7 cmol(+) kg^{-1} at the toe, and significantly lower at the other slope positions (Table 3-9). Cation exchange capacity of the B-horizon did not differ among crest, upper and middle slope positions. As expected from their differences in clay contents (Table 3-8) the CEC of the B-horizon exceeded that of the A-horizon by two to three times. Soil pH values were marginally different ($p = 0.047$) in the forest floor between middle and toe slope positions (Table 3-10), yet the crest and upper slope positions were similar ($p > 0.05$) to both the toe and middle slope positions. Difference ($p \leq 0.05$) in soil pHw was detected in the B-horizon toe slope position; it was greater than all the B-horizon pHw's at the top of the slope. Overall, the highest pHw values occurred in the C-horizon of all slope positions.

3.3.3 Soil properties and ecological response variables

Pearson's correlation was use to determine the strength of the relationship between ecological response variables and soil properties. The strongest relationships that existed for leaf area index (LAI) by forest floor and C-horizon bulk density (Figure 3-4 a,k). Leaf area index adjusted for conifer composition within the stand by basal area (LAI adj. BA) correlated better with forest floor bulk density (Figure 3-4 b). Leaf area index regressed on clay content of the B- and C-horizons were also relatively strong; using LAI adj. BA the relationship was improved for the clay-size fraction in the C-horizon (Figure 3-4 c,g,h). Leaf area index by permanent wilting point (mm; Figure 3-4 f) and silt content of the B-horizon were relatively strong, but the latter improved when regressed with LAI adj. BA (Figure 3-4 d,e). Silt content and soil pHw of the C-horizon were also relatively strong correlations (Figure 3-4 i,j).

3.4 Discussion

Toposequences were deemed to be similar according to the ecological response variables and individual soil properties. Evidence suggesting that the toposequence sites were different from one another was not strong, or not consistent among slope positions. The general similarity of the toposequences suggests that slope aspect is not a significant site property for tree growth, especially in comparison to slope position. Based on this information, slope positions were compared using plot data from all toposequences.

Slope position did have an effect on ecological response variables, but the significant differences were limited to LAI. Leaf area index was greater at the toe (bottom slope) than at upslope positions (crest, upper and middle slope). Also, evidence was found for slope position effect on examined soil chemical properties (see Chapter 4). Generally difference among slope positions for both ecological response variables and examined soil properties occurred between the top slope (crest, upper and middle) and bottom slope (toe) positions. Since differences primarily occurred between top and bottom slope positions for ecological response variables and soil properties the discussion will use the terms top slope and bottom slope when referring to trends. Ultimately, the objective of this study was to define the distribution of soil

properties and the effective depth (or volume) of soil where roots were capable of growing and therefore, to explain net plant community productivity.

In the literature, the depth of soil that is exploitable by plants is referred to as, effective rooting depth (Barnes *et al.*, 1998), and it is critical for determination of effective rooting volume. Determination of effective rooting depth (or volume) has been an influential soil property in many soil-site evaluation studies (Carmean, 1975; Carmean, 1996; Barnes *et al.*, 1998). Distribution of soil horizon thickness along with bulk density and other soil properties associated with particle size distribution are important because they physically describe the volume of soil, and properties of that volume, which provide conditions for plant growth.

Generally the observed trend in soil taxa along the centre transect soil profile descriptions supported data that indicated soil properties were different ($p \leq 0.05$). At the top of the slope the dominant soil taxa was Brunisolic Gray Luvisol (BR. GL) (Agriculture Canada Expert Committee on Soil Survey, 1987). At the bottom of the toposequences the soil taxa was either Gleyed Eluviated Eutric Brunisol (GLE. EB) or Orthic Luvic Gleysol (O. LG). The upper and middle slope soil taxa was typically Orthic Gray Luvisol (O. GL).

At the top of the toposequence sites the forest floor thickness was significantly less ($p \leq 0.05$) than the toe (Table 3-6), indicating different net rates of soil organic matter accumulation (see Chapter 4). Of course, this conclusion assumes the forest floor was completely eliminated by the fire that removed the previous forest stand, and that lower intensity fires since the stand's establishment have not affected the current forest floor. Both of these assumptions appear to be correct according to observations made during the selection of study sites, and during collection of forest stand and soil profile data (*e.g.*, there was no evidence of fire scars on trees or charcoal buried in the forest floor). For the mineral soil the colour, structure type and grade, horizon thickness and clay-size fraction of the A-horizon were different in the crest slope position compared to the toe (Table 3-8).

In this study the A-horizon bulk density ranged from 1.13 ± 0.14 to 1.20 ± 0.13 g cm^{-3} among slope positions (Table 3-7). The A-horizon is dominantly silt loam to loam which are coarse relative to the finer textured B-horizon (clay to clay loam) with bulk densities ranging from 1.47 ± 0.10 to 1.55 ± 0.08. Interestingly, bulk density was more influential on soil property distribution with depth, as opposed to distribution along the toposequence. A difference in horizon thickness of 10 to 12 cm, and 5 to 6 g $100g^{-1}$ of clay was detected ($p \leq 0.05$) among slope positions for A-horizon, but no difference was detected in the bulk density of the A- or B- horizons. This suggests bulk density is not as sensitive to varying intensities of clay translocation as other soil properties such as soil horizon thickness and particle size distribution. Bulk density only affects soil properties with depth. Increasing bulk density with depth is typical because of decreasing soil organic matter content, aggregation and root penetration, as well as increasing compaction due to overlying soil (Brady, 1990).

Particle-size distribution is related to the process of clay translocation (lessivage), especially when high clay-content soils are not dominated by clay mineralogical types prone to shrinking and swelling with water content changes. In the illuvial B-horizons, there was no detectable change ($p \leq 0.05$) in clay content or bulk density (Table 3-8 and 3-7), while the water contents varied from about 24 mm to 103 mm above water content at –1500 kPa between the top and bottom ($p \leq 0.05$) of the slope[2]. In the eluvial A-horizons the clay-size fraction was 8.9 ± 1.2 g $100g^{-1}$ at the crest, and increased toward the toe of the slope ($p \leq 0.05$). This result in conjunction with horizon thickness and bulk density influenced the potential volume of stored water available to plants by horizon along the toposequence. Plant-available water capacity (by volume) of the soil profile, *i.e.*, the volume of water held by matric forces (Ψm) between -33 and -1500 kPa within 1.20 m of the soil surface, was greatest in the top slope positions (Figure 3-3). However, in early-October the amount of available water within 1.20 m was greatest at the toe slope position with about 150 mm. In the breakdown by horizon most of the water content at greater than -1500 kPa was in the A- and C-horizons, with the exception of the C-horizon at the bottom of the slope (Figure 3-2 b,d). In the thick B-horizon, very little water was available for use by plants during early-October (Figure 3-2 c). Although it was not determined, the forest floors at all slope positions probably contributed very little to the horizon available water capacity, whereas the mineral soils contributed 270 to 320 mm (Figure 3-3).

Cation exchange capacity (cmol(+) kg^{-1}) of the A-horizon was different ($p \leq 0.05$) among the top and bottom landscape positions (Table 3-9). Soil pHw was marginally different among the A-horizons ($p = 0.047$) at the 95% confidence level (Table 10); the pHw was most acidic at the toe. In the C-horizon, the mean soil pHw for the toe was much greater than other slope positions (Table 3-10). It is possible that the relatively rapid change in soil pHw with depth at the toe of the slope is due to the white spruce plant community dominating litter additions at the toe, and the relatively close proximity of the calcareous C-horizon (pHw = 7.88 ± 0.08) to the mineral soil surface. Cation exchange capacity buffers soil acidity because clay surfaces have negatively charged sites that adsorb free cations in solution. In the A-horizon at the toe of the slope, clay content is significantly greater than at any other landscape position. Therefore cation exchange capacity buffering (by mass) soil acidity was greatest in the toe where white spruce dominates the stand. Toe sites are potentially better sites for the white spruce community production because the pH is beneficial to microbial activity, nutrient turnover, and root function. Sutton (1967) reported that good standard minimum pH requirements for white spruce is 4.7 to 6.5, and Stiell (1976) reported good growth in alkaline soils (Burns and Honkala, 1990a). However, Kishchuk (2000) indicated that forest productivity may be reduced in highly alkaline soils by chemical, physical and biological

[2] Water content was measured from bulk sample for horizons as well as the bulk density (Db) samples, both of which were collected during early-October, 1998.

process-based limitations. These minimum and maximum pH values also coincide with the generalized optimum range for the availability of N, P, K, and S as well as microbial activity (Brady, 1990).

The B-horizon cation exchange capacity was not different among slope positions, but B-horizon soil pHw was different. Soil pHw of the B-horizon at the toe was greater due, in part, to the change in the species composition and therefore forest floor litter composition which contributes to soil acidity (Brand *et al.*, 1986; Kimmins, 1987). The C-horizon soil pH was near neutral or only slightly alkaline compared to A- and B-horizons because of the calcareous nature of the parent geologic material at each slope position. On average, the calcareous parent geologic material was shallowest at the bottom of the landscape (Table 3-6). This suggested that the toe of the slope provides a better volume of soil for root exploitation due to soil properties and horizon thickness at the bottom of the slope compared to the top of the slope.

There was no visual evidence for separation of root abundance by slope position. Generally, roots of all diameters were concentrated in the forest floor and A-horizons (Figure 3-5). One possible reason for root abundance to be concentrated in the A-horizon is the effectiveness of the soil for providing conditions conducive to plant growth. Some qualities of the effective rooting volume were noted in the morphological descriptions of the soil profiles along the toposequence, and they appear to reflect the distribution of roots well. One of those soil properties is horizon bulk density. Root development appears to be influenced by bulk density; it decreases above and below a given range (Greacen and Sands, 1980). The effect of bulk density on root growth is thought to be an interaction of soil strength, available water and nutrients, and aeration. In central Alberta increased bulk density decreased white spruce seedling growth (Corns, 1988). In another study trembling aspen and white spruce root growth was concentrated at the organic/mineral horizon interface, and root densities were negatively correlated with depth and bulk density, and positively correlated with soil water-holding capacity (Strong and La Roi, 1985).

Compared to the B-horizon, the relatively thin, less-dense eluvial horizon had the greatest abundance of roots in all size classes (Table 3-7; Figure 3-5 a,b). The dominant orientation of the roots was horizontal, and roots were observed to penetrate soil aggregates (inped), and therefore potentially able to access a greater volume of soil within the A-horizons. In the more dense illuvial horizon (Bt) and parent geologic material few roots were found and nearly all were very-fine to medium in size; no coarse roots were found in the C-horizon (Table 3-7; Figure 3-5 c,d). In the lower horizons of the toposequence profiles, the roots were typically fewer, smaller and vertically oriented along ped surfaces potentially decreasing the actual volume of soil roots that can access for water and nutrients.

The root density distribution (Figure 3-5) appears to follow the available water (by volume) trend in early-October (Figure 3-3) along the toposequence. Available water was found in the A- and C-horizons; very little available water was found in the B-horizon except in the toe slope position. Compared to the A-horizon root density drops completely out of the abundant class and almost completely out of the

plentiful class in the B-horizon. Root density distribution does not reflect the amount of available water capacity (by volume) along the toposequence or by soil depth.

The silvics of the dominant tree species in part plays a role in the distribution of roots. In well-drained soils aspen typically develops deep tap and extensive lateral roots near the soil surface from which sinker roots drop and end with fine feeder-roots (Burns and Honkala, 1990b). In this study the aspen typically grow in the upper slope positions with no evidence of the water table within at least 1.5 m, and a 60 to 70 cm thick illuvial B-horizon with a dry hard to very hard consistence, and an average bulk density of 1.52 g cm^{-3}. In central Alberta, undisturbed Bt horizons with similar bulk densities to those in the B-horizon of this study imply that there are restrictions to tree root development according to Nadeau and Pluth (1997). Aspen trees dominate at the top of the slope and the combined effect of B-horizon thickness, structure, consistence, bulk density, and < 50 μm particle size fraction suggest the volume of the largest horizon in the soil profile is relatively ineffective for aspen tree growth. A conclusion supported by aspen silvicultural literature (Burns and Honkala, 1990b). In this study, the root density distribution suggests aspen that prefers low-density (Corns, 1988; Nadeau and Pluth, 1997), lower clay content of the thick A-horizon. White spruce will typically exploit the surface horizons with large roots concentrating "within the 15 cm (6 in.) of the organo-mineral soil interface" (Burns and Honkala, 1990a), and would not be expected to be as limited by the relatively ineffective B-horizon soil rooting volume.

The examined soil properties describe site conditions in the mixedwood stands of this project. Undesirable conditions were most prominent at the top of the slope. However, considering the A-horizon distribution of root abundance, low bulk density, the generally platy structure and very weak consistence as well as the volume of available water compared to the B- and C-horizon, the A-horizon may be the most effective soil rooting volume at the top of the slope.

Compared to the A-horizon, the B-horizon clay content was increased by of the illuviation of clay, and therefore its water content at -33 kPa and CEC were greater as well. Unfortunately, the B-horizon also had a greater water content at -1500 kPa, and higher bulk density than the A-horizon; the latter two soil properties may be the reason roots were not as concentrated in the B-horizon as compared to the A-horizon. Although, the rooting characteristics of the dominant tree species may also be a factor in determining root abundance in both A- and B- horizons. In general, the B-horizon also had a medium sub angular blocky to blocky structure with firm to very firm consistence that may actually reduce the effective soil volume for root development so that the estimate of effective soil volume by bulk density and thickness may be an over-estimate. Evidence for this is the dominance of exped only roots in the B-horizon. Overall, this suggests the B- and C-horizons were not as effective for root development as the A-horizon, especially in the top slope positions where the translocation of clay was most strongly expressed. Since the soil properties of the B- and C-horizon appear to create the largest and least effective volume of soil for root development, it is possible the response of the forest community productivity will be sensitive to changes in B- and C-horizon properties.

Correlations of ecological response variables with examined soil properties were used indicate the strength of relationships. Carmean's (1975) review of more than 100 soil-site studies suggested that soil depth, soil texture, pH and water factors were highly associated with site quality, especially for aspen and spruce. In this study, it was found that the A-horizon soil properties examined had very weak relationships with ecological response variables despite the apparent relative effectiveness of the A-horizon soil volume for supporting plant growth. The poor correlation between examined A-horizon soil properties and ecological response variables may be due to the greater variability expected to occur nearer to the surface of the mineral soil. The strongest relationships detected were in the lower horizons between ecological response variables, bulk density, and clay and silt contents. The exceptions were forest floor pH and bulk density, which did not have large spatial variations near the mineral soil surface at any slope position along the toposequence sites in this study. Pearson r-values indicated a negative trend for bulk density supporting the hypothesis that high bulk density may be correlated to the reduced effectiveness of the soil volume for plant growth. Some quantitative measurement of soil structure type and grade, and of consistence on root development within the soil may further explain the relationship between soil properties and forest community productivity.

3.5 Conclusions

What is the typical depth of forest floor and surface mineral soil horizons along toposequences of mixedwood stands in West-Central Alberta? Forest floor thickness increased from crest (5 ± 2 cm) to toe (9 ± 3 cm). In the mineral solum, the greatest horizon thickness was at the top of the slope. A-horizon thickness varied from 17 ± 8 cm (toe) to 29 ± 6 cm (crest), and B-horizon thickness varied from 61 ± 27 cm (toe) to 76 ± 23 cm (upper slope).

How are potentially important soil properties distributed along toposequences? Soil properties examined in this study suggest translocation of clays was the dominant process in the study area, and soil morphological observations suggest that the process was most strongly expressed at the top of the slope. The A-horizon clay content was greatest at the bottom of the slope, and in the B-horizon, it was greatest at the top. As a result the top of the slope had the greatest estimated available water capacity (by volume) and estimated cation exchange capacity (cmol(+) kg^{-1}). Despite available water capacity, the top slope had the least available water (in July and October) for plants, and the highest soil pH in the A- and B-horizons. The C-horizon soil pH was greatest in each profile, and again it was greatest at the bottom slope position.

How is forest productivity related to these individual soil properties? Any soil property examined of the A-horizon was weakly associated to ecological response variables of LAI and LAI adj. BA used as proxies for forest productivity. Forest floor pH and bulk density showed much stronger relationships with the ecological response variables. In the lower horizons, particle size distribution and pHw variables also showed strong relationships with ecological response variables.

Table 3-1. Physiographic and soil attributes of the three toposequence sites (mean ± SE)

Toposequence Attribute	Unit	Site 1 n = 15	Site 2 n = 12	Site 3 n = 12
Aspect		south	southeast	north
Maximum Slope Length	m	427	145	300
Mid Elevation, ASL	m	777	816	768
Total Change in Elevation	m	24	8	12
Forest Floor Thickness	cm	6.2 ± 0.7	5.8 ± 0.6	6.0 ± 1.1
Forest Floor Total C	kg m^{-2}	2.8 ± 0.4	1.9 ± 0.2	2.1 ± 0.5
A-horizon Total C	kg m^{-2}	2.3 ± 0.4	2.2 ± 0.6	1.4 ± 0.2

Table 3-2. Summary of forest community and stand attributes of the three toposequence sites in 1998 (mean ± SE).

Toposequence Attribute	Unit	Site 1 n = 15	Site 2 n = 12	Site 3 n = 12
Maximum Tree Age (at 1.3 m)	a deciduous/coniferous	104/88 crest/lower	93/78 crest/middle	80/94 middle/toe
Stand Composition by BA	% deciduous/ % conifer	66/34	45/55	40/60
Stand Density	trees ha^{-1}	1826	1293	2500
BA[a]	m^2 ha^{-1}	41 ± 2	38 ± 2	30 ± 3
BAI[b]	m^2 ha^{-1} a^{-1}	0.55 ± 0.04	0.59 ± 0.03	0.65 ± 0.06
LAI[c]	m^2 m^{-2}	2.7 ± 0.2	3.1 ± 0.2	3.1 ± 0.1

[a]BA – basal area at 1.3 m height
[b]BAI – mean annual basal area increment at 1.3 m height
[c]LAI – leaf area index above 1.3 m height.

Table 3-3. Two-way ANOVA models (eq. 3-5) for the comparison of ecological response variable values among toposequence sites (T) and slope positions (S).

Source of Variation	df	MS	Signif. of F
	LAI (m^2 m^{-2})		
T	2	0.762	0.020
S	3	1.089	0.002
T x S	6	0.827	0.002
Error	24	0.164	
	BA (m^2 ha^{-1})		
T	2	423.528	0.010
S	3	74.407	0.419
T x S	6	42.046	0.763
Error	24	75.972	
	BAI (m^2 ha^{-1} a^{-1})		
T	2	0.024	0.444
S	3	0.029	0.400
T x S	6	0.007	0.953
Error	24	0.028	

Table 3-4. Two-way ANOVA models (eq. 3-5) for the comparison of soil property values among toposequence sites (T) and slope positions (S).

Source of Variation	df	MS	Signif. of F
Horizon thickness (cm)			
Forest floor			
T	2	1.88	0.832
S	3	32.674	0.006
T x S	6	6.799	0.380
Error	24	6.062	
A-horizon			
T	2	75.528	0.014
S	3	247.583	0.000
T x S	6	177.528	0.000
Error	24	14.743	
Bulk Density (g cm^{-3})			
Forest floor			
T	2	0.004	0.000
S	3	0.000	0.928
T x S	6	0.000	0.386
Error	24	0.000	
A-horizon			
T	2	0.137	0.001
S	3	0.009	0.574
T x S	6	0.012	0.549
Error	24	0.014	
B-horizon			
T	2	0.000	0.975
S	3	0.015	0.094
T x S	6	0.005	0.604
Error	24	0.006	
Clay Content (g 100g^{-1})			
A-horizon			
T	2	59.305	0.009
S	3	77.517	0.001
T x S	6	14.070	0.270
Error	24	10.336	
B-horizon			
T	2	697.511	0.001
S	3	98.689	0.277
T x S	6	185.440	0.046
Error	24	72.184	
Silt Content (g 100g^{-1})			
A-horizon			
T	2	403.922	0.003
S	3	277.075	0.008
T x S	6	94.653	0.164
Error	24	55.578	
B-horizon			
T	2	129.718	0.089
S	3	263.351	0.005
T x S	6	51.105	0.392
Error	24	124.374	
Sand Content (g 100g^{-1})			
A-horizon			
T	2	552.706	0.001
S	3	512.537	0.000
T x S	6	90.866	0.205
Error	24	58.582	
B-horizon			
T	2	233.539	0.015
S	3	50.474	0.375
T x S	6	274.336	0.001
Error	24	46.584	

Table 3-4. Continued

Source of Variation	df	MS	Signif. of F
Moisture Content 29 to 31 July 1998 (cm^3 $100cm^{-2}$)			
Forest Floor			
T	2	4698.846	0.006
S	3	4620.897	0.003
T x S	6	926.513	0.323
Error	27	754.470	
A-horizon			
T	2	327891.959	0.000
S	3	94347.096	0.037
T x S	6	85705.889	0.025
Error	22	27939.912	
Moisture Content 12 to 15 August 1998 (cm^3 $100cm^{-2}$)			
Forest Floor			
T	2	8752.720	0.001
S	3	7491.052	0.001
T x S	6	1324.882	0.272
Error	27	985.731	
Moisture Content 7 to 13 October 1998 (cm^3 $100cm^{-2}$)			
A-horizon			
T	2	40515.824	0.704
S	3	80021.086	0.559
T x S	6	106819.889	0.485
Error	27	114089.949	
B-horizon			
T	2	941165.685	0.134
S	3	613790.442	0.261
T x S	6	1371495.663	0.018
Error	27	434643.606	
Available Water Capacity (cm^3 $100cm^{-2}$)			
A-horizon			
T	2	90048.581	0.000
S	3	62766.995	0.001
T x S	6	90692.581	0.000
Error	27	8651.533	
B-horizon			
T	2	2325370.926	0.002
S	3	954654.873	0.036
T x S	6	2706521.484	0.000
Error	27	291706.537	

Source of Variation	df	MS	Signif. of F
Cation Exchange Capacity (cmol (+) kg^{-1})			
A-horizon			
T	2	12.674	0.009
S	3	16.580	0.001
T x S	6	3.009	0.271
Error	24	2.212	
B- horizon			
T	2	149.213	0.001
S	3	21.109	0.277
T x S	6	39.671	0.046
Error	24	15.436	
Soil pH in water (pHw)			
Forest Floor			
T	2	3.920	0.000
S	3	0.643	0.047
T x S	6	0.080	0.880
Error	22	0.207	
A-horizon			
T	2	3.317	0.000
S	3	0.376	0.194
T x S	6	0.044	0.974
Error	24	0.222	
B-horizon			
T	2	0.472	0.417
S	3	4.583	0.000
T x S	6	0.245	0.824
Error	24	0.521	

Table 3-5. Comparison of ecological response variables by slope position with pooled toposequence site data (mean ± SE).

Slope Position	BA[a] $m^2\ ha^{-1}$	BAI[b] $m^2\ ha^{-1}\ a^{-1}$	LAI[c] $m^2\ m^{-2}$
Crest	32.2 ± 4.3	0.54 ± 0.05	2.8 ± 0.2a
Upper Slope	35.6 ± 3.0	0.57 ± 0.11	2.7 ± 0.2a
Middle Slope[d]	39.4 ± 1.8	0.58 ± 0.03	2.9 ± 0.1a
Toe	37.4 ± 2.9	0.69 ± 0.08	3.5 ± 0.2b

Note: Within-column means with the same letter are not different, p = 0.05

[a]BA – basal area at 1.3 m height

[b]BAI – mean annual basal area increment at 1.3 m height

[c]LAI – leaf area index above 1.3 m height.

[d]Middle slope position n = 12, not 9 like other slope positions

Table 3-6. Comparison of soil horizon thickness (cm; mean ± SE) among slope positions and associated two-way ANOVA p-values.

	Crest n = 9	Upper n = 9	Middle n = 12	Toe n = 9	p-value
Forest Floor	5 ± 1a	5 ± 1a	6 ± 1a	9 ± 1b	0.006
A-horizon	29 ± 2b	19 ± 3a	22 ± 2a	17 ± 3a	0.000
B-horizon	64 ± 7	76 ± 8	65 ± 1	61 ± 9	NA[a]
C-horizon[b]	23 ± 6	24 ± 8	29 ± 2	32 ± 11	NA

Note: Within-row means with the same letter are not different, p = 0.05

[a]NA indicates not available

[b] sampled to a profile depth of 1.2 m; n = 3

Table 3-7. Comparison of soil bulk density (mean ± SE) among slope positions, with two-way ANOVA p-values.

	Crest n = 9	Upper n = 9	Middle n = 12	Toe n = 9	p-value
			$Mg\ m^{-3}$		
Forest Floor	0.09 ± 0.01	0.09 ± 0.01	0.10 ± 0.01	0.09 ± 0.01	0.928
A-horizon	1.18 ± 0.03	1.13 ± 0.02	1.20 ± 0.02	1.15 ± 0.05	0.574
B-horizon	1.55 ± 0.03	1.50 ± 0.03	1.47 ± 0.03	1.55 ± 0.02	0.094
C-horizon[a]	1.62 ± 0.09	1.57 ± 0.11	1.63 ± 0.11	1.59 ± 0.05	NA[b]

[a]Sample size of C-horizon: Crest n = 3, Upper n = 3, Middle n = 4, and Toe n = 3; sampled to a profile depth of 1.2 m.

[b]NA indicates not available

Table 3-8. Comparison of soil particle-size classes (clay <2 μm, silt 50-2μm, and sand 2000-50μm; mean ± SE, g $100g^{-1}$) among slope positions, with two-way ANOVA p-values.

	Crest n = 9	Upper n = 9	Middle n = 12	Toe n = 9	p-value
			Clay		
A-horizon	8.9 ± 1.2a	9.4 ± 1.1a	9.9 ± 1.2a	15.0 ± 1.5b	0.001
B-horizon	43.2 ± 3.7	40.5 ± 2.2	45.7 ± 4.3	37.1 ± 4.0	0.277
C-horizon[a]	42.6 ± 6.5	40.1 ± 0.9	37.7 ± 1.1	32.5 ± 4.8	NA
			Silt		
A-horizon	57.1 ± 2.7b	57.3 ± 2.5b	48.0 ± 3.3a	59.9 ± 3.0b	0.008
B-horizon	31.6 ± 1.5a	36.2 ± 2.3ab	31.5 ± 1.8a	43.4 ± 3.4b	0.005
C-horizon[a]	30.2 ± 2.4	33.5 ± 1.9	34.6 ± 1.9	38.2 ± 3.9	NA
			Sand		
A-horizon	34.1 ± 3.4ab	33.3 ± 1.9b	42.1 ± 3.7b	25.1 ± 3.2a	0.000
B-horizon	25.2 ± 3.5	23.3 ± 3.5	22.8 ± 3.5	19.5 ± 2.7	0.375
C-horizon[a]	27.2 ± 8.6	26.4 ± 1.2	27.7 ± 2.9	29.3 ± 5.5	NA[b]

Note: Within-row means with the same letter are not different, p = 0.05

[a]Sample size of C-horizon: Crest n = 3, Upper n = 3, Middle n = 4, and Toe n = 3; sampled to a profile depth of 1.2 m.

[b]NA – not available

Table 3-9. Comparison of estimated soil cation exchange capacity (mean ± SE) among horizons and slope positions, with two-way ANOVA p-values.

	Crest n = 9	Upper n = 9	Middle n = 12	Toe n = 9	p-value
			cmol (+) kg^{-1}		
A-horizon	6.6 ± 0.6a	6.8 ± 0.5a	7.0 ± 0.5a	9.4 ± 0.7b	0.001
B-horizon	22.5 ± 1.7	21.2 ± 1.0	23.6 ± 2.0	19.6 ± 2.0	0.277
C-horizon[a]	22.2 ± 3.0	21.0 ± 0.4	19.9 ± 0.5	17.5 ± 2.2	NA[b]

Note: Within-row means with the same letter are not different, p = 0.05

[a]Sample sizes: Crest n = 3, Upper n = 3, Middle n = 4, and Toe n = 3.

[b]NA – not available

Table 3-10. Soil pH in distilled water (mean ± SE) compared among slope positions, with two-way ANOVA p-values.

	Crest n = 9	Upper n = 9	Middle n = 12	Toe n = 9	p-value
Forest Floor	5.62 ± 0.26ab	5.65 ± 0.24ab	6.12 ± 0.13b	5.41 ± 0.23a	0.047
A-horizon	5.51 ± 0.18	5.47 ± 0.20	5.44 ± 0.15	5.82 ± 0.28	0.194
B-horizon	5.07 ± 0.08a	5.19 ± 0.05a	5.42 ± 0.16a	6.61 ± 0.40b	0.000
C-horizon[a]	6.63 ± 0.77	5.91 ± 0.47	6.35 ± 0.58	7.88 ± 0.08	NA[b]

Note: Within-row means with the same letter are not different, p = 0.05

[a]Sample size of C-horizon: Crest n = 3, Upper n = 3, Middle n = 4, and Toe n = 3.

[b]NA – not available

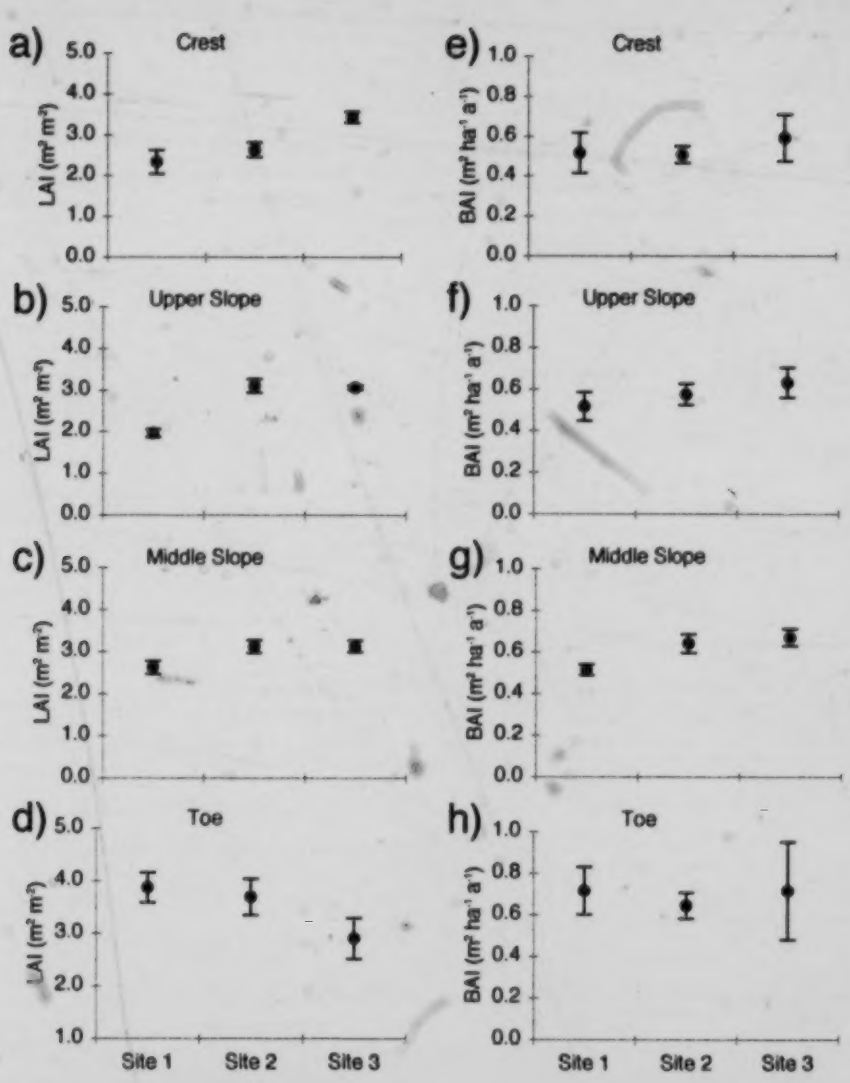

Figure 3-1. Leaf area index (LAI) and mean annual basal area increment (BAI) as ecological response variables (mean ± SE) compared among toposequence sites according to slope position.

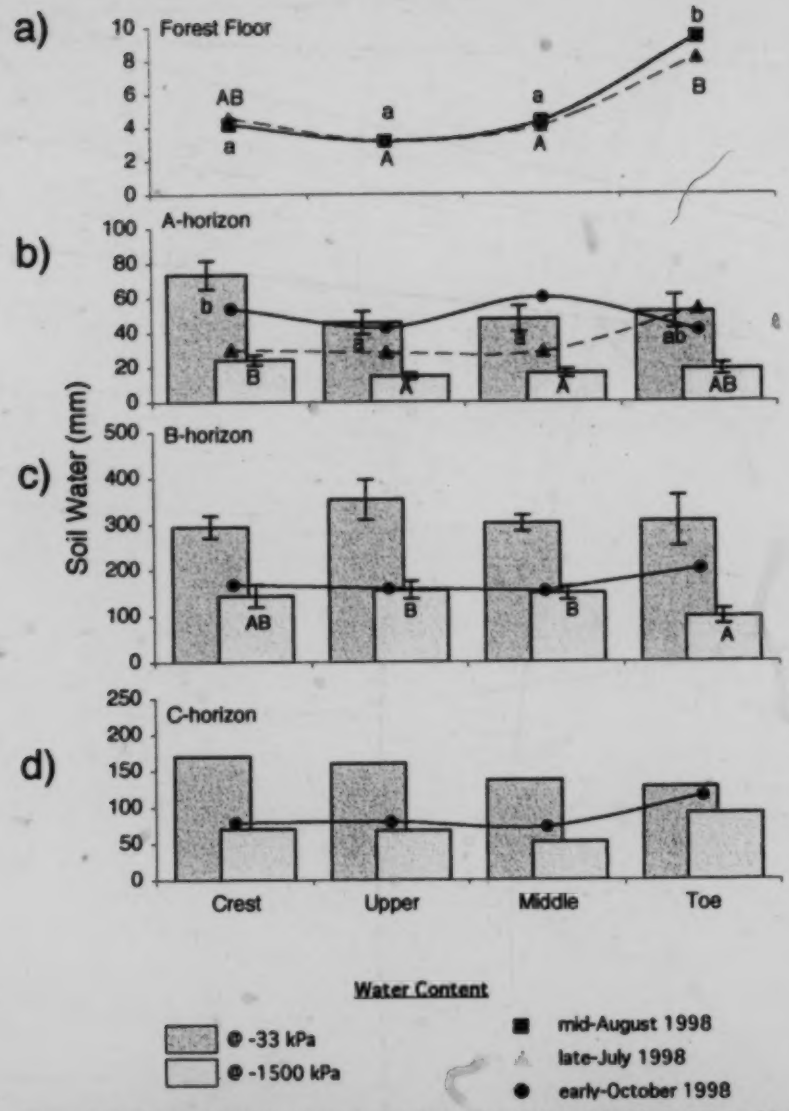

Figure 3-2 Volumetric water content of a) forest floor in late-July (dashed line with triangle; upper case) and mid-August (solid line with square; lower case). For b) A-horizon, c) B-horizon and d) C-horizon; volumetric soil water content in late-July (dashed line with triangle) and early-October (solid line with circle), and estimated available water capacities between -33 and -1500 kPa matric potential (mean ± SE) to a mineral profile depth of 1.20 m. For water content at -33 kPa (lower case) and -1500 kPa (upper case) the same letter indicates values are not different ($p \leq 0.05$). No estimate of error for the C-horizon is available because of lack of replication.

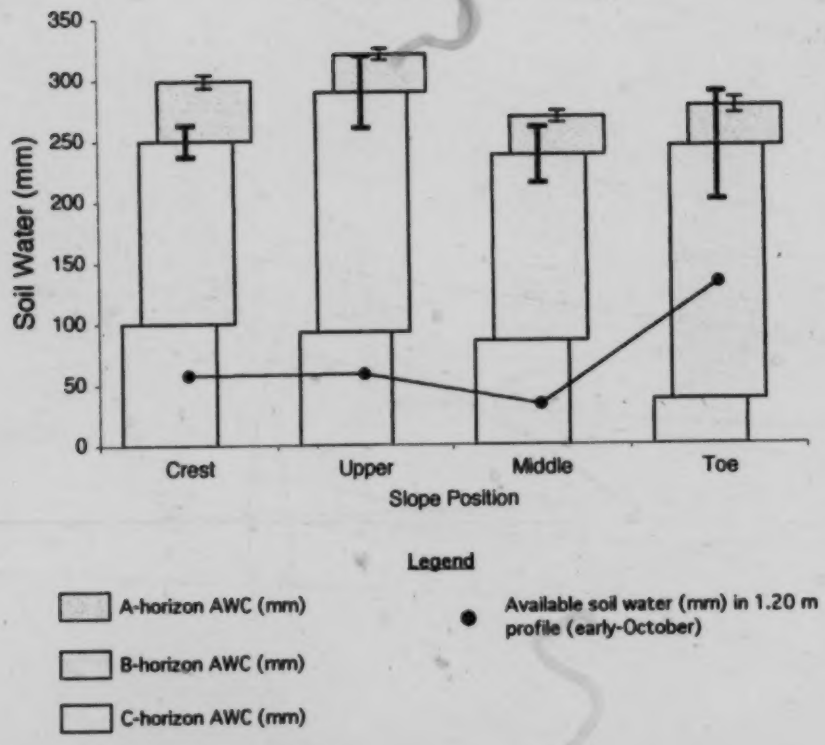

Figure 3-3. Cumulative available water capacity (AWC; mean ± SE) to 1.20 m depth in the mineral soil profiles at the crest, upper, middle, and toe slope positions. Overlaid is the available soil water for the profile at each slope position during early-October (1.20 m depth). No estimate of error for the C-horizon is available because of lack of replication.

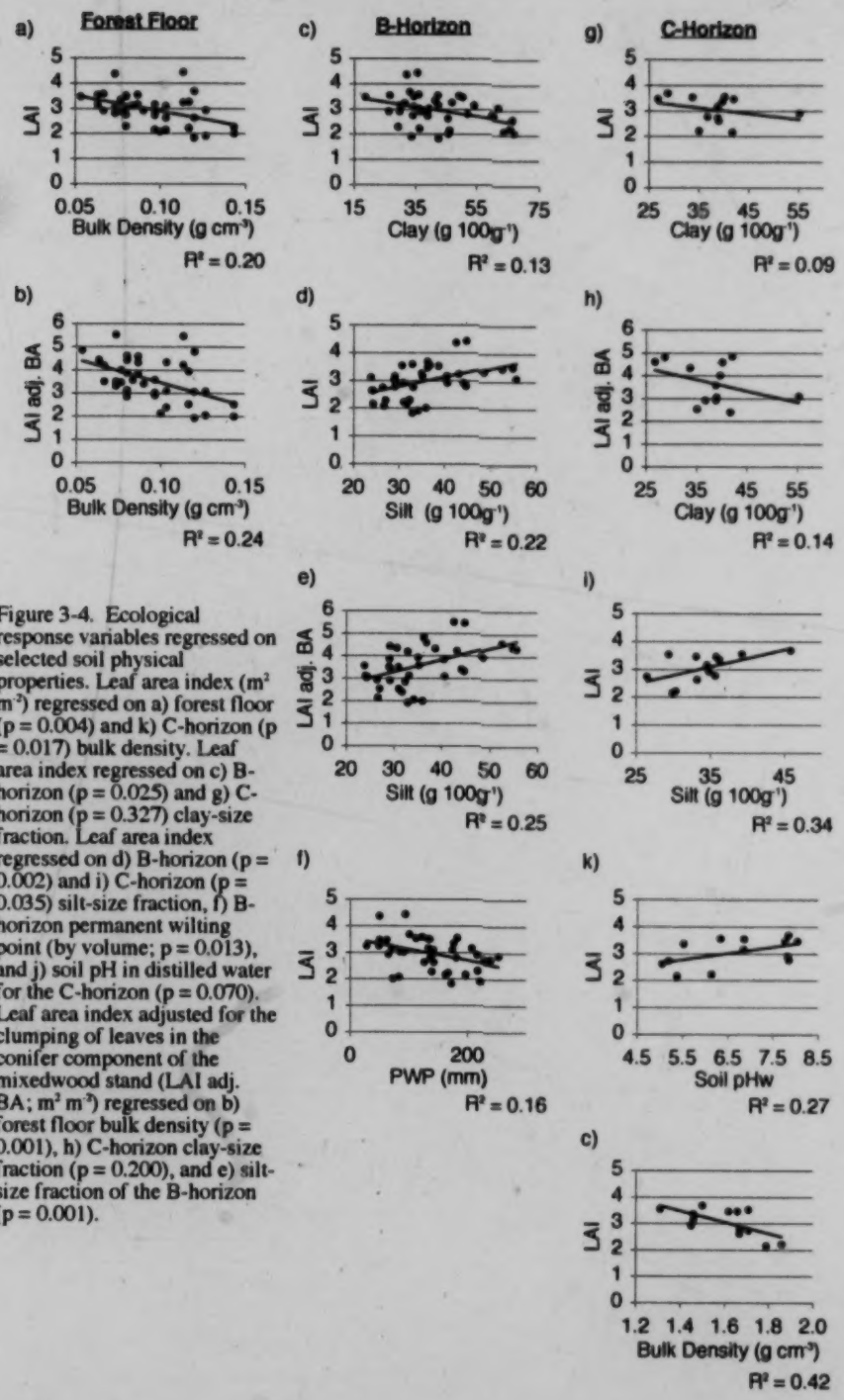

Figure 3-4. Ecological response variables regressed on selected soil physical properties. Leaf area index (m^2 m^{-2}) regressed on a) forest floor ($p = 0.004$) and k) C-horizon ($p = 0.017$) bulk density. Leaf area index regressed on c) B-horizon ($p = 0.025$) and g) C-horizon ($p = 0.327$) clay-size fraction. Leaf area index regressed on d) B-horizon ($p = 0.002$) and i) C-horizon ($p = 0.035$) silt-size fraction, f) B-horizon permanent wilting point (by volume; $p = 0.013$), and j) soil pH in distilled water for the C-horizon ($p = 0.070$). Leaf area index adjusted for the clumping of leaves in the conifer component of the mixedwood stand (LAI adj. BA; m^2 m^{-3}) regressed on b) forest floor bulk density ($p = 0.001$), h) C-horizon clay-size fraction ($p = 0.200$), and e) silt-size fraction of the B-horizon ($p = 0.001$).

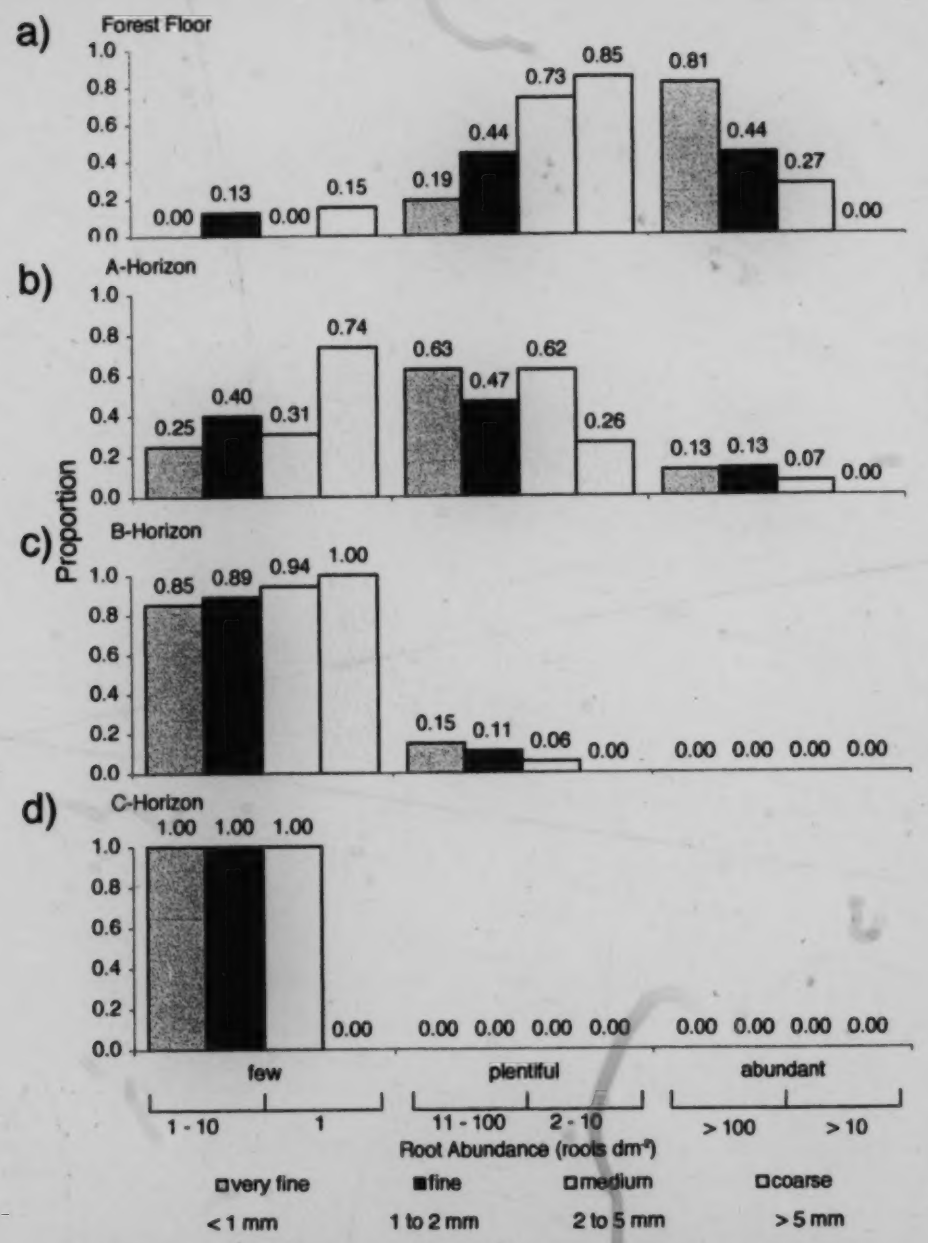

Figure 3-5. Frequency of root size class, as a proportion of the total number of subhorizon observations within a size class, sorted by abundance classes for the a) forest floor, b) A-horizon, c) B-horizon, and d) C-horizon to a mineral soil depth of 1.20 m. Within in a horizon, the summation of proportions of abundance classes within a size class is equal to one.

3.6 Literature cited

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. Res. Br. Agric. Canada, Minister of Supply and Services Canada, Ottawa. Publ. No. 1646. 164 pp.

Amponsah, G. I. 1998. Forest soil characteristics and variability under teak (*Tectona grandis* Linn. F) plantations and national forests in Ashanti region, Ghana. Unpubl. M. Sc. thesis. Lakehead Univ., Thunder Bay, Ontario. 88 pp.

Barnes, B. V., D. R. Zak, and S. R. Denton. 1998. Forest ecology. 4th. John Wiley & Sons, New York. 774 pp.

Beckingham, J. D., I. G. W. Corns, and J. H. Archibald. 1996. Field guide to ecosites of west-central Alberta. Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent., Edmonton. Special Rept. 9.

Brady, N. C. 1990. The nature and properties of soils. 10th. Collier Macmillian Pub., London. 621 pp.

Brand, D. G., P. Kehoe, and M. Connors. 1986. Coniferous afforestation leads to soil acidification in central Ontario. Can. J. For. Res. **16**: 1389-1391.

Brown, K. M. 1994. Design and analysis of experiments: a short course for forestry practitioners. Lakehead University, Thunder Bay, Ontario. 221 pp. (Unpublished manuscript)

Burns, R. M., and B. H. Honkala. 1990a. Silvics of North America: Vol. 1, Conifers. U. S. D. A., For. Serv., Agric. Handbook No. 654. 675 pp.

Burns, R. M., and B. H. Honkala. 1990b. Silvics of North America: Vol. 2, Hardwoods. U. S. D. A., For. Serv., Agric. Handbook No. 654. 877 pp.

Cameron, D. R., M. A. Nyborg, J. A. Toogood, and D. H. Laverty. 1971. Accuracy of field sampling for soil tests. Can. J. Soil Sci. **51**: 165 - 175.

Carmean, W. H. 1975. Forest site quality evaluation in the United States. Adv. Agron. **27**: 209 - 267.

Carmean, W. H. 1996. Forest site-quality estimation using forest ecosystem classification in Northwestern Ontario. Environ. Monit. Assess. **39**: 493 - 503.

Chen, J. M. 1996. Optically-based methods for measuring seasonal variation of leaf area index in boreal conifer stands. Agric. For. Meteorol. **80**: 135 - 163.

Corns, I. G. W. 1988. Compaction by forestry equipment and effects on coniferous seedling growth in four soils in the Alberta Foothills. Can. J. For. Res. **18**: 75 - 84.

Craig, R. F. 1983. Soil mechanics. 3rd. Van Nostrand Reinhold (UK) Co. Ltd., Birkshire. 419 pp.

Culley, J. L. B. 1993. Density and compressibility. Ch. 50. pp. 529 - 539. *In* Soil sampling and methods of analysis. Carter, M. R. Ed. Lewis, London. 1995. 823 pp.

Curtin, D., and H. P. W. Rostad. 1997. Cation exchange and buffer potential of Saskatchewan soils estimated from texture, organic matter and pH. Can. J. Soil Sci. **77**: 621 - 626.

Day, P. R. 1965. Particle fractionation and particle size analysis. Ch. 43. pp. 545 - 567. *In* Methods of soil analysis part 1. Black, C. A., D. D. Evans, J. L. White, L. E. Ensminger and F. E. Clark Eds. American Society of Agronomy, Madison. Vol. 1. 1965. 770 pp.

Environment Canada. 1998. Canadian Climate Normals 1961 to 1990. www.cmc.ec.gc.ca/climate/normals/E_AL_NDX.HTM. Accessed: 15 November, 2000. Environment Canada.

Gower, S., and J. M. Norman. 1991. Rapid estimation of leaf area index in conifer and broad-leaf plantations. Ecology **72**: 1896 - 1900.

Greacen, E. L., and R. Sands. 1980. Compaction of forest soils. A review. Aust. J. Soil Res. **18**: 163 - 189.

Hall, R. J. 1998a. LAI measurment in mixedwood forest stands. Email, Thursday, June 11, 1998, 1:14 PM.

Hall, R. J. 1998b. Special lecture - leaf area index ver. 1.1. Nat. Resour. Can., Can. For. Serv., North. For. Cent. Lecture, August 1998.

Helling, C. S., G. Chesters, and R. B. Corey. 1964. Contribution of organic matter and clay to soil cation-exchange capacity as affected by pH and saturating solution. Soil Sci. Soc. Am. Proc. **28**: 517 - 520.

Husch, B., C. I. Miller, and T. W. Beers. 1982. Forest mensuration. 3rd. John Wiley & Sons, New York. 402 pp.

Johnson, R. A., and G. K. Bhattacharyya. 1992. Statistics: principles and methods. 2nd. John Wiley & Sons, New York. 686 pp.

Kalra, Y. P., and D. G. Maynard. 1991. Methods manual for forest soils and plant analysis. For. Can., Northwest Reg., North. For. Cent., Edmonton. Info. Rept. No. NOR-X-319. 116 pp.

Kimmins, J. P. 1987. Forest ecology. Collier Macmillian Pub., London. 531 pp.

Kishchuk, B. E. 2000. Calcareous soils, their properties and potential limitations to conifer growth in southeastern British Columbia and western Alberta: a literature review. Northern Forestry Center, Canadian Forestry Service, Info. Rept. No. NOR-X-370. 21 pp.

Kodama, H. 1979. Clay minerals in Canadian soils: their origin, distribution and alteration. Can. J. Soil Sci. **59**: 37 - 58.

Li-Cor Inc. n.d. The LAI-2000 Plant Canopy Analyzer. Li-Cor Inc., Lincoln.

MacDonald, B. G. 1995. The case for boreal mixedwood management: an Ontario perspective. For. Chron. **71**: 725 - 734.

Marshall, T. J., J. W. Holmes, and C. W. Rose. 1996. Soil Physics. 3rd. Cambridge University Press, Cambridge. 453 pp.

McClave, J. T., and F. H. Dietrich II. 1991. Statistics. Collier MacMillian Canada, Toronto. 928 pp.

Metz, L. J., C. G. Wells, and B. F. Swindel. 1966. Sampling soil and foliage in a pine plantation. Soil Sci. Soc. Am. Proc. **30**: 397-399.

Microsoft. 1998. Microsoft Excel 98 Macintosh Edition.

Nadeau, L. B., and D. J. Pluth. 1997. Spatial distribution of lodgepole pine and white spruce seedling roots 10 years after deep tillage of a Gray Luvisol. Can. J. For. Res. **27**: 1606 - 1613.

Petersen, L. W., P. Moldrup, O. H. Jacobsen, and D. E. Rolston. 1996. Relations between specific surface area and soil physical and chemical properties. Soil Sci. **161**: 9-21.

Ryan, T. P. 1997. Modern regression methods. John Wiley & Sons, Inc., Toronto. 515 pp.

Sheldrick, B. H., and C. Wang. 1993. Particle size distribution. Ch. 47. pp. 499 - 511. *In* Soil sampling and methods of analysis. Carter, M. R. Ed. Lewis, London. 1995. 823 pp.

Soil Science Society of America. 1998. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 15 November, 2000. Soil Science Society of America.

Soil Survey Staff. 1998. Keys to soil taxonomy. 8th. U.S. Dept. of Agric., Nat. Resour. Conserv. Serv., Washington, D.C. 326 pp.

SPSS. 1995. SPSS 6.1.1 for Power Macintosh.

St. Arnaud, R. J., and G. A. Sephton. 1972. Contribution of clay and organic matter to cation exchange capacity of chernozemic soils. Can. J. Soil Sci. **52**: 124 - 126.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics. 2nd. McGraw-Hill, New York. 633 pp.

Stiell, W. M. 1976. White Spruce: artificial regeneration in Canada. Forest Management Institute, Canada, Info. Rept. No. FMR-X-85. 275 pp.

Strong, W. L., and G. H. La Roi. 1985. Root density - soil relationships in selected boreal forests of central Alberta, Canada. For. Ecol. Manage. **12**: 233 - 251.

Sutton, R. F. 1967. Influence of root pruning on height increment and root development of out planted white spruce. Can. J. Botany **45**: 1671-1682.

Twardy, A. G., and I. G. W. Corns. 1980. Soil survey and interpretations of the Wapiti map area, Alberta. Alberta Res. Coun., Edmonton, Alberta, 134 pp.

Verma, T. R. 1968. Moisture balance in soils of the Edmonton area. Unpubl. Ph. D. dissertation. Univ. of Alberta, Edmonton, Alberta.

Chapter 4

Post-Fire Forest Floor Development along Toposequences of White Spruce - Aspen (*Picea glauca – Populus tremuloides*) Mixedwood Communities in West-Central Alberta[1]

4.1 Introduction

Fire in the boreal forest is a natural disturbance that can dramatically affect the forest floor and ultimately nutrients available for surviving or regenerating plants. The return cycle of fire in the boreal forest varies widely. In the western Canadian boreal forest the fire cycle was reported to be 40 to 60 years (Mann and Plug, 1999), which is somewhat shorter than the 50-100 year interval reported by Nalder and Wein (1999) and the 50 to 150 year interval reported by Van Cleve *et al.* (1991). Fire recurrence in other parts of the Canadian boreal forest was between 30 and 80 years (Bergeron and Brisson, 1990; Desponts and Payette, 1992). Furthermore, Harden *et al.* (2000) has suggested from reviewed literature that, compared to studies pertaining to fire in the 19th century, regions other than eastern Canada are showing increasingly extensive fires in the post-1980 period. Whether or not fires are becoming more extensive in the western Canadian boreal forest, they will continue to occur in the future and can be expected to affect the forest floor and nutrient availability.

The degree of severity with which fires in the boreal forest affect the forest floor is highly variable, which was explicitly noted by Dyrness and Norum (1983). Variation in climate and water content immediately prior to burning can result in radical changes in post-burn severity classes. Dyrness and Norum (1983) reported a 27.4 % reduction in the forest floor thickness in the most lightly burned area (*i.e.*, only 11.2 % of the area classified as, moderately to heavily burned) in black spruce (*Picea mariana* Mill. BSP) – feathermoss forests which included the occasional group of trembling aspen and paper birch (*Betula papyrifera* Marsh.). In the most heavily burned area, which was 77.2 % moderately and heavily burned, there was a 63.1 % decrease in the average forest floor thickness. Similar results were in other literature (Dyrness *et al.*, 1989).

The reduction in the forest floor caused by fire affects the amount of soil organic matter (C) and the availability of nutrients. In the western boreal forest one study reported that the forest floor represents 33 % of the C stored in the boreal aspen forests (Nalder and Wein, 1999). Another study supports this result; 47.3 % of the soil organic C in 1.0 m soil profiles was found in the L, F, and H horizons of boreal aspen stands in central Saskatchewan (Huang and Schoenau, 1996). Partial reduction or complete

removal of forest floor thickness by fire can therefore be expected to impact the overall soil organic matter (C) content. Soil organic matter plays an important role in recovery after disturbance; organic matter is a major source of plant community nutrient elements, including N, S and P. Many studies have been done to understand the cycling of these nutrient elements and the influence of organic matter on plant community production. In a literature review, Johnson (1992) found that light to moderate burns tended to be beneficial for growth of the recovering forest, and speculated that the reason could be the mobilization of nutrients stored in organic matter. Severely burned sites were thought to be depleted in nutrients due to volatilization. Almost 10 years later, Johnson and Curtis (2001) revisited the literature review to add new information, and used meta-analysis to analyze multiple independent studies. They came to the same conclusion that C and N in the A-horizon increases 10 years after disturbance.

After a high severity fire the accumulation of organic matter (and nutrients) in the forest floor begins again with the re-establishment of forest litter deposition and subsequent decomposition. The development of the post-fire forest floor is determined by the net rate of soil organic matter accumulation. The rate of soil organic matter accumulation depends on 1) rates of organic matter addition and 2) the rate of decomposition. The former is influenced by site productivity. The latter is the primary factor, after wildfire, that reduces soil C (Trettin *et al.*, 1999) and is mostly a function of substrate quality, temperature, and moisture (Meentemeyer, 1978; Meentemeyer and Berg, 1986; Taylor *et al.*, 1991; Berg *et al.*, 1993; Moore *et al.*, 1999).

According to Hobbie *et al.* (2000), substrate quality is a highly influential parameter for decomposition; in some cases it is more influential than temperature in the boreal forest regions. The selective decomposition of soil organic matter substrates may be categorized into three types. Readily decomposed organic matter type consists of simple and complex sugars, and amino acids (Brady, 1990; McColl and Gressel, 1995; McLaren and Cameron, 1997). Moderately decomposable organic matter consists of cellulose and hemicellulose, and recalcitrant organic matter is composed of lipids and lignin. In separate studies by Hobbie *et al.* (2000) and Moore *et al.* (1999), temperature was as important as substrate quality in the boreal forest. Increase in soil temperature increases the activity of soil microorganisms exponentially (Waring and Schlesinger, 1985) within temperature ranges common to the boreal forest. In soil organic matter decomposition models, microbial death rate is inversely associated with soil moisture (Van Veen *et al.*, 1984).

The amount of soil organic C in the boreal forest of western Canada appears to vary according to studies. Across a range of climate zones in the western Canadian boreal forest Nalder and Wein (1999) reported an average 2.78 kg C m^{-2} in the forest floor under aspen stands. Huang and Schoenau (1996) reported a range of 3.38 to 5.79 kg C m^{-2} in the forest floor with a mean thickness of 0.10 m, and 3.90

---

[1] A version of this chapter has been submitted for publication in the Canadian Journal of Forest Research

to 6.47 kg C m^{-2} in 1.0 m mineral soil profiles under aspen dominated forest. The aim of this study was to answer the following questions:

1. What are the various sizes of soil organic C and N pools in selected boreal mixedwood forests of west-central Alberta;
2. How are they distributed spatially along toposequences; and
3. How is forest productivity correlated to organic C and N pool sizes and distribution?

4.2 Materials and methods

4.2.1 Study area

The study area (54°40'N, 118°13'W, 787 ± 26 m ASL) was approximately 70 km southeast of Grande Prairie, Alberta. It falls within the Lower Foothills Natural Sub-region (Beckingham *et al.*, 1996), and lies on the border of the Wapiti Plains and the Alberta Benchland Plateau physiographic region of the Interior Plains (Twardy and Corns, 1980). This area has rolling relief (Agriculture Canada Expert Committee on Soil Survey, 1987), and is comprised of glaciolacustrine, till and glaciofluvial materials deposited during the late Pleistocene epoch (Twardy and Corns, 1980).

The soils typical of the study area are Gray Luvisols (Twardy and Corns, 1980; Agriculture Canada Expert Committee on Soil Survey, 1987), or Haplocryalfs (Soil Survey Staff, 1998). The soils of this study conform to the specifications of the Donnelly soil group. The Donnelly soil group is derived from glaciolacustrine or lacustrotill deposits (Twardy and Corns, 1980). The Donnelly soil group includes Orthic Gray Luvisols (O. GL) and Orthic Luvic Gleysols (O. LG) in the lower slope positions "where groundwater discharge and surface waters tend to accumulate" (Twardy and Corns, 1980).

Regional climate of the study area is continental, *i.e.*, long, cold winters and mild summers (Twardy and Corns, 1980). The climate of the Lower Foothills Natural Sub-region is characterized by a mean annual temperature of 3.0 °C, and total annual precipitation of 464 mm (Beckingham *et al.*, 1996). Grande Prairie, Alberta is the nearest full-time weather station to the study area (Grande Prairie A, Station Id#: 3072920, 55°11' N, 118°53' W, 666 m ASL). The mean annual temperature for Grande Prairie is 1.6 °C and the total annual precipitation was 450.2 mm (308.6 mm rainfall) based on 30 years of data (Environment Canada, 1998).

The study area is classified as boreal mixedwood, which is characteristic of the Lower Foothills Natural Sub-region (Beckingham *et al.*, 1996). Predominant vegetation at the top slope position is typically white spruce (*Picea glauca* (Moench) Voss) and trembling aspen (*Populus tremuloides* Michx.) with an understory dominated by the shrub green alder (*Alnus crispa* (Ait.) Pursh) and bracted honeysuckle (*Lonicera involucrata* (Richards.) Banks). Toe slope positions are dominantly white spruce and black spruce (*Picea mariana* (Mill.) BSP) with Labrador tea (*Ledum groenlandicum* Oeder), feather moss (generally *Ptilium*, *Pleurozium* and *Hylocomium* spp.) or *Sphagnum* ground cover.

4.2.2 Sampling design

To achieve the objective of this study, prospective toposequences were sampled within the study area. A toposequence was defined as a consecutive series of topographic positions (Beckingham *et al.*, 1996). Toposequences were selected to meet several criteria. First, they were examined to ensure there were no recent disturbances, such as human activity, disease, insect damage/defoliation, or fire since stand origin. Second, the forest was to be dominantly spruce and aspen mixedwood. Third, the stands were to be uniform in age along a given toposequence. Finally, trees along toposequences should not be degrading as a result of old age, but near to the optimum rotation age with a full canopy.

Three toposequences were used as study sites: Site 1 was 350 m long and varied between 765 m and 789 m above sea level (ASL) (24 m relief). Site 2 was 130 m long and its elevation varied from 812 m to 820 m ASL (8 m relief). Site 3 was 290 m in length; and the top and bottom slope elevations were 762 m to 774 m (12 m relief).

Toposequence sites were subdivided into transects (3), transect positions, and plots. Three nearly parallel transects separated by 15 m to 30m were established for replicated sampling of slope position within a toposequence site. Plots were the sampling locations along each transect within a toposequence site (Figure 2-5). In the terrain of this study the lower slope position was not sampled on all toposequence sites as a result of the proximity of adjacent plots. Therefore, only the crest, upper, middle and toe slope positions were used to compare toposequence sites. In all comparisons, the middle slope positions had an unbalanced sample size because Site 1 had two transect positions that met the form criteria of middle slope.

Also, following completion of soil morphological description and sampling, specific mineral soil horizons were aggregated into one of three horizon categories based on genetic features (Agriculture Canada Expert Committee on Soil Survey, 1987). The aggregate categories were as follows: 1) A-horizon, including all A-horizon variations (Ah, Ahe, Ae, *etc.*) occurring in a soil profile, the AB transition horizon if present, and a Bm or a Bf developed in the A-horizon zone of polygenetic soil profiles *e.g.*, the Bm in a Brunisolic Gray Luvisol (BR. GL), and the Bf in a Podzolic Gray Luvisol (PZ. GL); 2) B-horizon including variations of the horizon (Bt_1, Bt_2, Btnj, Bg, *etc.*) occurring in the soil profile and the BC transition horizon if present; 3) C-horizon, containing all variations of the horizon *e.g.*, Ck, Cca and Cg *etc.*

4.2.3 Ecological response variables of forest mixedwood communities

Stand data were collected from plots (sites). Stand-level variables such as effective leaf area index[2] (LAI), basal area (BA), tree density and age were used to assess similarity of toposequence sites. Basal

[2] Effective leaf area index (LAI) value as measured by the Li-Cor 2000 Plant Canopy Analyzer (Gower and Norman, 1991; Chen, 1996; Hall, 1998b; Li-Cor Inc., n.d.). It may be abbreviated eLAI, LAI_e, or L_e in other literature.

area, mean annual increment of BA and LAI were also used as estimates of net primary productivity 1.3 m above the forest floor.

Net primary productivity is a fundamental measure of forest-site productivity (Soil Science Society of America, 1998b). It is the rate of plant biomass accumulation after losses due to consumption and respiration. Productivity is the rate of accumulation of a specified material (Kimmins, 1987), and in this study it refers more specifically to tree and shrub net biomass by excluding biomass under 1.3 m height (breast height). Effective leaf area index, basal area, and basal area increment will be referred to as ecological response variables because they are surrogates for net primary production in response to site conditions.

Leaf area index as a proxy of the site net primary productivity, was measured by a LAI-2000 Plant Canopy Analyzer (Li-Cor Inc., Lincoln, Nebraska). Within plot measurements were taken from nine locations (8 at every 45° azimuth along the plot perimeter plus one at plot center) to estimate effective LAI per 100 m^2 square plot. Measurements were taken only when continuous and uniform cloud cover occurred during the period from 25 to 31 August 1998 between 8 AM and 4 PM, immediately prior to the first evidence of leaf abscission. Continuous and uniform cloud cover during the day provided uniform light conditions for measurements. Light intensity readings required about 10 min per plot: about four minutes for diffuse light (Q_i) within plot (n = 9), and about six minutes to traverse between the plot and an area with no overhead cover (Q_o).

Leaf area index was adjusted by basal area (LAI adj. BA) for species composition (*i.e.*, proportion of coniferous component) of the sample site (plot; eq. 3-1). The adjustment was necessary since the Li-Cor LAI-2000 instrument underestimates LAI by 35 to 40% (Gower and Norman, 1991; Hall, 1998a; Hall, 1998b).

The forest stand parameters of basal area, tree height, tree diameter outside bark (dbhob), sapwood area, and age at 1.3 m above ground level (breast height) were collected from sample trees selected by the point sample method (Husch *et al.*, 1982). These data sets were collected between 27th August and 14th September 1998. Only plot centers nearest to the midpoints of the crest, lower slope, toe and depression positions of the slope were sampled to prevent repeated measurement of large sample trees from adjacent within-transect positions. Tree age was estimated from tree cores extracted at 1.3 m.

4.2.4 Soil properties

Soils were characterized by a pedon description and from horizon samples at each plot along the center transect (Agriculture Canada Expert Committee on Soil Survey, 1987). Intensity of soil sampling varied by horizon depth according to the general knowledge of horizontal and vertical spatial variability of soil properties (Metz *et al.*, 1966; Cameron *et al.*, 1971; Blyth and MacLeod, 1978; Amponsah, 1998).

Forest floor and mineral soil samples for determination of organic C and total N were collected in the fall of 1998 and air-dried immediately after returning from the field. The forest floor samples were

cut into approximately 1 mm pieces in the Wiley Mill, and then ground to a fine powder (<2 μm) in a ball grinder. The mineral soil structure was broken with a wooden rolling pin, and passed through a 2 mm sieve. The fine portion of the mineral soil was ground to a fine powder in a ball grinder. The samples were then weighed and combusted in the mass spectrometer.

Organic-C and total N pools of the forest floor and mineral horizons were calculated for each horizon (m/v; *i.e.*, unit mass per unit volume) using independent estimates of the element content, horizon thickness and bulk density (see Chapter 3). Horizon thickness for the lateral transect plots was assumed to be the same as those reported in the morphological description for the specific center transect position and toposequence site. Although sampling intensity was greatest for the forest floor and A-horizons, only mean values of each were used to calculate one horizon estimate per plot. The C/N ratios are based on mass.

Net N mineralization rates were estimated by *in-situ* incubation of unmixed core samples of forest floor (225 cm^2) and of the upper 10 cm of A-horizon. About one-half of a core sample was retained for an estimate of initial inorganic-N and the remainder was returned to its horizon position in a polyethylene bag *ca.* 11 μm thick (Dow Customer Service, 1998). The *in-situ* incubation of the forest floor material were duplicated in space (2 per plot) and time (first set installed 27th to 31st July and removed 12th to 15th August; second set installed 12th to 15th August and removed on the 31st). One A-horizon core sample was incubated per plot between the 27th July and 31st August 1998. At a more southern location, 50 km west of Edmonton, mean August soil temperature was 14°C at 10 cm depth in Gray Luvisolic soils and closed tree canopy, indicating that near-surface temperatures would likely peak during early to mid-August in our study area (Macyk *et al.*, 1978).

All soil samples were stored in the field at 3 to 6 °C for 4 days or less, then stored at –9 °C in the laboratory, until extraction of NH_4^+ and NO_3^-. The KCl-extracted NH_4^+ and NO_3^- concentrations were quantified by autoanalyzer (Maynard and Kalra, 1993).

Bulk density was determined for the forest floor and mineral horizons. The forest floor was sampled by systematically removing 900 cm^2 and recording undisturbed horizon thickness. Mineral horizons were sampled by using a Uhland corer (331 cm^3). Dry bulk density was determined according to the procedure outlined by Culley (1993). It involved drying mineral soil samples at 105°C to constant weight. Organic horizon materials (L, F, and H) were dried at 75°C to constant weight.

4.2.5 Statistical analyses

Analysis of variance (McClave and Dietrich II, 1991; Johnson and Bhattacharyya, 1992) was performed using SPSS 6.1.1 (SPSS, 1995). Two-way analysis of variance (two-way ANOVA) was used on ecological response and soil property variables to determine differences among toposequence sites (eq. 4-1). The null hypothesis was that toposequence sites were not different. Two-way ANOVA was also

used to test the difference between slope positions. The null hypothesis was that there was no difference among slope positions for soil properties.

[4-1] $$Y_{ijk} = \mu + T_i + S_j + TS_{ij} + \varepsilon_{(ij)k}$$

where Y_{ijk} is the response for the *k*th plot within *j*th slope position within *i*th toposequence site, μ is the grand mean, T_i is the fixed effect of the *i*th toposequence site, and S_j is the fixed effect of the *j*th slope position (crest, upper, middle or toe). The TS_{ij} term is the fixed effect of the interaction between the *i*th toposequence site and the *j*th slope position, and $\varepsilon_{(ij)k}$ is the fixed effect of the *k*th plot within the *j*th slope position within the *i*th toposequence site. The assumptions for the analysis of variance were that the experimental errors are random, normally and independently distributed with a zero mean and common variance (Steel and Torrie, 1980; McClave and Dietrich II, 1991).

Microsoft Excel 98 was used to perform t-tests, assuming unequal variance, and to generate Pearson correlation matrices (Microsoft, 1998). The t-tests with the assumption of unequal variance were used because of the variance trend; variances increased from crest slope position to toe slope position. The t-tests identified differences among slope positions detected by ANOVA. Analyzing toposequence sites independently was not necessary because they were generally similar in ecological response variables and individual soil properties, according to two-way ANOVA. Therefore, the comparison of slope positions was accomplished by using all the toposequences together, and gave 9 observations per crest, upper and toe positions and 12 observations per middle slope position.

4.3 Results

4.3.1 Toposequence sites

Toposequence sites have different slope aspects and slope lengths, however their elevations were similar (Table 3-1). Stand and soil attributes are also similar among the three toposequence sites (Tables 3-1 and 3-2).

The maximum age for toposequence sites was used to estimate the time since the last presumed stand-originating fire (Table 3-2). Maximum mean time elapsed since the last stand-originating fire is 92 ± 12 years. This estimate was based on the maximum age of deciduous trees, which were typically aspen. Maximum deciduous ages occurred in the crest, upper and middle slope positions on all toposequences. The difference in maximum ages, *i.e.*, deciduous age minus coniferous age was 16, 15 and −14 years for sites 1, 2, and 3 respectively. The older coniferous age at Site 3 may indicate a residual tree that survived the stand-originating fire, as the maximum tree age occurred at the lowest slope position of a north facing aspect.

Boreal stands in which no single species exceeds 80% of the BA is considered mixedwood (MacDonald, 1995). Percent stand composition was calculated from toposequence BA (Table 3-2), and all

three toposequence sites qualify as boreal mixedwood stands by this criterion. Mean conifer species composition, by BA, for all toposequences by slope position were 30, 36, 42 and 79% for crest, upper, middle, and toe positions respectively. Deciduous trees were typically trembling aspen and coniferous trees were typically white spruce. Sub-dominant tree species were typically balsam poplar (*Populus balsamifera* L.) and black spruce (*Picea mariana* (Mill.) BSP).

For the comparison of toposequence sites a two-way ANOVA was used (eq. 4-1). Only LAI and organic C in the B-horizon had significant interactions of site and slope position (Tables 3-3 and 4-1). The LAI interaction ($p = 0.002$) was expressed as 2.90 ± 0.39 m^2 m^{-2} at the toe of the slope of Site 3, which was much lower than the same slope positions of Site 1 (3.87 ± 0.39) and Site 2 (3.69 ± 0.35). The main effect of site LAI ($p = 0.02$) was less detectable than the interaction, and was caused by Site 1, which was nearly 0.5 m^2 m^{-2} less than Sites 2 and 3. Figure 3-1 (a,b,c,d) shows mean LAI among sites by slope positions. The mean basal area of Site 3 was about 11 m^2 ha^{-1} less than that of sites 1 and 2, differences were detectable only by the two-way ANOVA ($p = 0.01$). The interaction of site and slope position for organic C in the B-horizon ($p = 0.006$) was due to the toe of Site 3 having about 9 kg m^{-2} more C than any other slope position on any site. Also, the mean organic C of Site 3 was 1.7 kg m^{-2} more than the other two sites. The mean C/N ratio of the forest floor was greatest at Site 2 by about 3, and in the A-horizon the C/N ratio of Sites 2 and 3 were greater than Site 1 by about 8. There were no other differences detected among sites by BAI (Table 3-3), or for the remaining soil properties by horizon (Table 4-1).

4.3.2 Slope position

Leaf area index (LAI) was the only ecological response variable that was different among slope positions ($p = 0.02$; Table 4-1). Overall, the mean LAI of the toe slope position was 3.5 m^2 m^{-2}, which was at least 0.6 m^2 m^{-2} greater ($p \leq 0.05$) than any of the upslope positions (crest, upper and middle). The effect of slope position on the soil properties was also tested for each horizon (eq. 4-1). The null hypothesis was that slope position does not influence organic-C, total N, C/N ratio, the rate of specific or net mineralized N, or the NO_3-N/NH_4-N ratio. Results indicate differences ($p \leq 0.05$) between two or more slope positions for organic-C in the forest floor, A- and B-horizons (Table 4-2, Figure 4-1 a,b,c,d). Generally, the accumulation of organic-C increased from crest to toe only in the forest floor, A- and B-horizons. In the A-horizon, total N by mass was greatest ($p = 0.030$) at the toe position (Tables 4-3). Total N, by volume, in the A-horizon was greatest ($p = 0.022$) at the crest slope position (Table 4-4). Forest floor and A-horizon C/N values at the toe were about 4.6 and 2.5 greater than all the upslope positions (Table 4-5). There were no detectable changes by slope position for the rate of net N mineralized (by mass) or rate of specific net N mineralized (Tables 4-6 and 4-7), and there were no detectable differences among slope positions for the rate of net N mineralization (by volume; Table 4-8).

No differences were detected among slope positions for forest floor or A horizon for NO_3-N/NH_4-N ratio (Table 4-9).

4.3.3 Organic C, C/N ratios and net mineralized N and ecological response variables

Pearson's correlation was used to determine the strength of relationships between leaf area ecological response variables and soil properties. Both LAI and LAI adjusted for the proportion of the conifer component in the stand, according to basal area (LAI adj. BA) were used in the correlation matices, since the Li-Cor LAI-2000 has been shown to underestimate spruce LAI by up to 40% (Gower and Norman, 1991). Soil properties with the strongest slope position effect according to the two-way ANOVA also showed the strongest correlation with leaf area ecological response variables. The correlation of LAI and C/N ratio of the forest floor and A-horizon produced Pearson r's of 42.7% ($p = 0.007$, Figure 4-2 a) and 29.0% ($p = 0.074$, Figure 4-2 b). Pearson r-values for the C/N ratios were improved by using LAI adj. BA for the forest floor; $r = 58.4\%$ ($p = 0.001$, Figure 4-2 c), and A-horizon $r = 0.38$ ($p = 0.016$, Figure 4-2 d). Organic C was weakly correlated with the leaf area ecological response variables since all p-values were > 0.05, but total N (g $100g^{-1}$) had an $r = -49.3\%$ ($p = 0.001$, Figure 4-2 e) for LAI adj. BA. Correlation statistics for leaf area ecological response variables and C-horizon soil properties were not reported because of small sample sizes.

4.4 Discussion

Ecological response variables (Table 3-3) and soil physical properties (Table 3-4) were found to be relatively similar among toposequence site. In this study soil chemical properties were examined for differences among toposequence sites (Table 4-1), but detected differences were generally not very strong, or consistent among slope positions. Based on the relatively weak and inconsistent differences among toposequences the ecological response variable and soil property data for all three toposequence sites were used to compare slope positions for each horizon.

Slope position did have an effect on ecological response variables, but the significant differences were limited to LAI (Table 3-3). The difference detected in the LAI was between the toe (bottom slope) and all of the upslope positions (crest, upper and middle slope) (Table 3-5). Based on this result the discussion will focus on differences between the top and bottom slope.

In the forest floor, soil organic C (kg m^{-2}) and C/N ratio were different along the slope. The trends of organic C accumulation among slope positions for each major soil horizon, except the C-horizon, were similar to those of the ecological response variables. The differences were between the bottom and the top of the slope. The forest floor at the toe slope position had a net accumulation of 1.4, 1.7 and 1.3 kg m^{-2} more C than the crest, upper and middle slope positions respectively, during the last 90 years. The difference between the amount of organic C stored in the forest floor at the top of the slope compared to the bottom most likely results from differences in the processes of decomposition.

The C/N ratio and rate of net N mineralization may explain a part of the difference in the processes of decomposition between the top and bottom of the slope. The C/N ratio is lowest at the top of the slope and there is a relatively large amount of N being mineralized (Table 4-8), suggesting C has become limiting to microbial growth and decomposition activity. The opposite scenario is occurring at the bottom of the slope. The C/N ratio is higher and the rate of net N mineralization is lower: data indicate that net immobilization of N is more common at the bottom compared to the top slope. This indicates that microbial activity is vigorous, since microorganisms are assimilating N in order to exploit the C substrate. N availability to higher plants at the bottom of the slope should be limited by the vigorous activity of the microorganisms, but this contradicts the ecological response variable data. The LAI ecological response variables indicate that the bottom of the slope is more productive than the top.

The net accumulation of forest floor organic C during the last 90 years, approximately, is likely a result of the rate of litter contributions to the forest floor as well as the rate of decomposition. The greater accumulation of organic C at the bottom of the slope may result from forest litter accumulating faster than microbial populations can decompose the plant material. This makes sense of the productivity data and the organic C pool, C/N ratio and net N mineralization data. According to Van Cleve and Powers (1995), plant productivity, which generates forest litter, is the primary source of soil organic C. More fresh plant matter, with high C/N ratios, means more vigorous microbial activity. As a result there is net immobilization, or a minimal amount of net N mineralized. However this does not explain: why the microorganisms cannot decompose organic matter as quickly as it becomes available, or why the productivity is greater at the bottom of the slope. A possible explanation is the differences in composition of the plant material that has been contributed to the forest floor, and the difference in the soil moisture and temperature regimes among slope positions.

The species composition of the mixedwood community influences the type of litter contributing to the forest floor organic matter pool. In the definition of a mixedwood forest, the percentage composition of conifer and deciduous trees is quite variable (MacDonald, 1995). In this study, there are more deciduous trees at the top of the slope, and more conifer trees at the bottom. This means that the amount of readily decomposable organic matter compared to recalcitrant forms is also different. Typically there is less recalcitrant material in aspen and birch litter relative to white spruce and black spruce (Van Cleve and Powers, 1995). As a result the bottom of the slope may have a greater amount of litter material with a slower turnover rate (*i.e.*, longer mean residence time). The recalcitrant organic matter is stored in the form of humus, which improves some site conditions for higher plants.

Humus that remains in the forest floor influences soil properties. The humus fraction is composed of: humin which is not soluble in water; humic acid, which is soluble in water at pH < 2; and fulvic acid which is soluble in water at any pH (McColl and Gressel, 1995; Paul and Clark, 1996). This is important because of the ability of the soluble humus fractions to solubilize metals and facilitate their movement from forest litter into in mineral soil (McColl and Gressel, 1995). In addition, humus buffers

soil acidity and provides a large amount of CEC to retain important elements in the labile[3] pool. In the A-horizon humus positively affects soil aggregate stability, aeration, water holding capacity and permeability with respect to plant productivity (Fisher, 1995). Figure 4-1 shows the amount of accumulated organic C by horizon, and that the largest pool at any depth is in the bottom slope position. Despite the apparent association of organic matter to productivity; it has not been well defined. Fisher (1995) claims that, "A cardinal reason is that in wetter soils growth often declines as soil organic matter content increases with increased wetness while drier soils the reverse is generally true".

The net accumulation of forest floor organic C may also be influenced by the differences in the soil moisture and temperature regimes among slope positions. Soil moisture content can be expected to increase, and soil temperature can be expected to decrease between the top and bottom of the slope (Macyk *et al.*, 1978). Periodic fluctuations of soil moisture content at the bottom slope are indicated by gleying and mottling, which were seen in the soils of the toe slope position. Gleying and mottling are a product of microbial activity, using Fe_3^+ as an electron acceptor under anaerobic conditions, and denotes a different pathway for the production of energy by microorganisms. It is called facultative anaerobic respiration and indicates limited aerobic decomposition of soil organic matter. That means there may be a greater rate of net soil organic matter accumulation. Similarly, temperature will limit microbial activity to a shorter period of the year than the top of the slope, and it will result in a greater rate of accumulation.

Generally, the correlations of soil organic C, C/N ratio and net N mineralized with ecological response variables were weak. However, among those three variables there is some evidence that forest floor C/N ratio could be useful for the estimation of ecological response variables (Figure 4-2).

4.5 Conclusions

Do ecological response variables and soil properties indicate toposequence sites are different, and is there a difference between slope positions? Toposequence sites were relatively similar according to ecological response variables and soil properties examined (Tables 3-3, 3-4 and 4-1). Any evidence of differences among the sites was not strong or consistent. Pooled toposequence LAI data indicate the toe slope position had a greater LAI than the others.

What are the various sizes of organic C pools in mixedwood forests of west-central Alberta, and how are organic C and N distributed along toposequences? Mean soil profile organic pools varied between 13.3 and 21.2 kg C m^{-2} to a depth of 1.2 m for the top and bottom of the slope respectively (Figure 4-1), and organic C pools of the forest floor, A- and B-horizons increased from crest to toe slope positions (Table 4-2). The widest C/N ratios by horizon were at the bottom of the slope (toe slope position; Table

[3] A description of substances that are readily transformed and available to plants (Brady, 1990). The amount of an element in the soil solution that is readily solubilized or exchanged (Soil Science Society of America, 1998a)

4-5); and the lowest rate of net N mineralization, as an indication of N, for plant growth was at the bottom of the slope. Rate of specific net N-mineralized was not different among slope positions (Table 4-7; $p \leq 0.05$); this result is similar to the findings in another study in fire-origin aspen-white spruce and black poplar-white spruce in central Alberta (Offord, 1999)

How is forest productivity correlated to pool size and distribution of organic C and total N? There was very little evidence of correlation between ecological response variables examined and organic C pools of any soil horizon or profile. Leaf area index adjusted for deciduous-coniferous species composition correlated positively with C/N ratio of the forest floor and A-horizons, and negatively with percent N of the forest floor (Figure 4-2).

Table 4-1. Two-way ANOVA models (eq. 4-1) for the comparison of soil property values among toposequence sites (T) and slope positions (S).

Source of Variation	df	MS	Signif. of F
Horizon thickness (cm)			
Forest floor			
T	2	1.88	0.832
S	3	32.674	0.006
T x S	6	6.799	0.380
Error	24	6.062	
Organic carbon (kg m^{-2})			
Forest floor			
T	2	3.408	0.086
S	3	5.377	0.015
T x S	6	1.272	0.439
Error	24	1.253	
A-horizon			
T	2	0.434	0.820
S	3	9.178	0.015
T x S	6	0.819	0.885
Error	24	2.164	
B-horizon			
T	2	45.282	0.041
S	3	51.387	0.016
T x S	6	50.769	0.006
Error	24	12.333	
Total N (%) or (g 100g^{-1})			
Forest floor			
T	2	0.581	0.000
S	3	0.076	0.073
T x S	6	0.093	0.019
Error	24	0.029	
A-horizon			
T	2	0.012	0.136
S	3	0.019	0.030
T x S	6	0.007	0.280
Error	24	0.005	

Source of Variation	df	MS	Signif. of F
Total N (kg m^{-2})			
Forest floor			
T	2	0.015	0.003
S	3	0.003	0.189
T x S	6	0.002	0.328
Error	24	0.002	
A-horizon			
T	2	0.006	0.487
S	3	0.029	0.022
T x S	6	0.010	0.282
Error	24	0.008	
C/N Ratio			
Forest floor			
T	2	295.621	0.000
S	3	73.376	0.003
T x S	6	26.647	0.079
Error	24	12.135	
A-horizon			
T	2	40.516	0.000
S	3	23.364	0.002
T x S	6	3.909	0.408
Error	24	3.657	
B-horizon			
T	2	23.171	0.296
S	3	62.502	0.032
T x S	6	7.778	0.852
Error	24	18.091	
Net Mineralized N (μg (g soil)$^{-1}$ 14d^{-1})			
Forest floor			
T	2	11467.693	0.230
S	3	12829.736	0.184
T x S	6	9931.413	0.273
Error	24	7336.053	
Net Mineralized N (μg (g soil)$^{-1}$ 14d^{-1})			
A-horizon (0 to 10 cm)			
T	2	3.565	0.088
S	3	2.739	0.130
T x S	6	1.183	0.509
Error	24	1.308	

Table 4-1. Continued

Source of Variation	df	MS	Signif. of F
Specific Net Mineralized N ($mg\ (g\ Total\ N)^{-1}\ 14d^{-1}$)			
Forest floor			
T	2	22.582	0.449
S	3	47.854	0.183
T x S	6	37.878	0.260
Error	24	27.280	
A-horizon (0 to 10 cm)			
T	2	1.660	0.410
S	3	3.626	0.138
T x S	6	0.740	0.863
Error	24	1.793	
Net Mineralized N ($mg\ m^{-2}\ 14d^{-1}$)			
Forest floor			
T	2	28421.248	0.567
S	3	20831.623	0.736
T x S	6	40868.960	0.555
Error	24	48936.792	
A-horizon (0 to 10 cm)			
T	2	54971.753	0.062
S	3	21925.796	0.311
T x S	6	20293.088	0.357
Error	22	17321.365	
NO_3-N/NH_4-N Ratio			
Forest floor			
T	2	0.009	0.727
S	3	0.008	0.842
T x S	6	0.042	0.241
Error	27	0.029	
A-horizon (0 to 10 cm)			
T	2	9.152	0.309
S	3	7.812	0.387
T x S	6	6.411	0.534
Error	23	7.404	

Table 4-2. Organic-C Pools for each slope position by soil horizon and profile total (mean ± SE)

	Crest	Upper	Middle[a]	Toe	p-value
		kg m^{-2}			
Forest Floor	2.0 ± 0.4a	1.7 ±0.4a	2.1 ± 0.3a	3.5 ± 0.5b	0.015
A-horizon	3.9 ± 0.3b	2.7 ± 0.4a	2.8 ± 0.2a	4.9 ± 0.8b	0.015
B-horizon	4.9 ± 0.3a	6.7 ± 0.8b	5.5 ± 0.6ab	10.1 ± 2.9ab	0.016
C-horizon[b]	3.4	3.5	2.9	2.70	NA[c]
Total 1.2 m soil profile	14.1	14.6	13.3	21.2	NA[c]

Note: Within row means with the same letter are not different, p = 0.05

[a]middle slope position n = 12, not 9 like other slope positions

[b]C-horizon Crest and Upper n = 2, and Middle and Toe n = 3; to a depth of 1.20 m.

[c]NA indicates not applicable

Table 4-3. Total N (g 100g^{-1}; mean ± SE) with one-way ANOVA p-values for comparison within slope position.

	Crest	Upper	Middle[a]	Toe	p-value
		Total N (%) or (g 100g^{-1})			
Forest Floor	1.55 ± 0.14	1.59 ± 0.06	1.58 ± 0.07	1.38 ± 0.05	0.073
A-horizon	0.10 ± 0.01	0.11 ± 0.02	0.10 ± 0.01	0.19 ± 0.05	0.030
B-horizon	0.08 ± 0.01	0.08 ± 0.00	0.09 ± 0.01	0.09 ± 0.00	NA[b]
C-horizon[c]	0.08	0.08	0.08	0.07	NA[b]

[a]middle slope position n = 12, not 9 like other slope positions

[b]NA not applicable

[c]C-horizon Crest and Upper n = 2, and Middle and Toe n = 3; to a depth of 1.20 m.

Table 4-4. Total N (by volume; mean ± SE) with two-way ANOVA p-values for comparison of slope positions.

	Crest	Upper	Middle[a]	Toe	p-value
		kg m^{-2}			
Forest Floor	0.08 ± 0.02	0.07 ± 0.02	0.09 ± 0.01	0.12 ± 0.02	0.189
A-horizon	0.32 ± 0.03b	0.20 ± 0.02a	0.24 ± 0.02a	0.31 ± 0.05ab	0.022
B-horizon	0.75 ± 0.04	0.97 ± 0.13	0.88 ± 0.06	0.85 ± 0.15	NA[b]
C-horizon[c]	0.46	0.44	0.42	0.35	NA[b]

Note: Within row means with the same letter are not different, p = 0.05

[a]middle slope position n = 12, not 9 like other slope positions

[b]NA not applicable

[c]C-horizon Crest and Upper n = 2, and Middle and Toe n = 3; to a depth of 1.20 m.

Table 4-5. C/N ratios (mean ± SE) with two-way ANOVA p-values for comparison within slope position.

	Crest	Upper	Middle[a]	Toe	p-value
Forest Floor	28.0 ± 2.3a	26.2 ± 1.4a	25.9 ± 1.5a	32.6 ± 2.0b	0.003
A-horizon	12.3 ± 1.0a	13.1 ± 0.9a	11.8 ± 0.6a	15.6 ± 0.6b	0.002
B-horizon	6.7 ± 0.2	7.1 ± 0.6	6.4 ± 0.2	11.7 ± 2.6	0.032
C-horizon[c]	7.4	7.7	7.2	9.0	NA[b]

Note: Within row means with the same letter are not different, p = 0.05

[a]middle slope position n = 12, not 9 like other slope positions

[b]NA not applicable

[c]C-horizon Crest and Upper n = 2, and Middle and Toe n = 3; to a depth of 1.20 m.

Table 4-6. Rate of net N-mineralization (μg (g soil)$^{-1}$ 14d^{-1}; mean ± SE) with two-way ANOVA p-values for comparison of slope positions.

	Crest	Upper	Middle	Toe	p-value
		μg (g soil)$^{-1}$ 14d^{-1}			
Forest Floor	-6.83 ± 18.93	53.34 ± 33.13	62.36 ± 34.14[a]	6.40 ± 10.68	0.184
A-horizon 0-10 cm	1.55 ± 0.53[b]	1.41 ± 0.37	0.99 ± 0.36	0.38 ± 0.35	0.130
Total	-5.45 ± 18.62	54.74 ± 32.96	63.10 ± 34.01	6.78 ± 10.65	0.178

Note: Forest Floor mean is the average of two 14 day periods; A-horizon mean is for one 14 day period.

[a]Forest floor Middle position n= 12, not 9 like other slope positions

[b]A- horizon Crest position n = 8, not 9 like other slope positions

Table 4-7. Rate of specific net N-mineralization (mg (g Total N)$^{-1}$ 14d^{-1}; mean ± SE) with two-way ANOVA p-values for comparison of slope positions.

	Crest	Upper	Middle	Toe	p-value
		mg (g Total N)$^{-1}$ 14d^{-1}			
Forest Floor	-0.923 ± 1.621	3.312 ± 2.075	3.343 ± 1.754[a]	0.402 ± 0.789	0.183
A-horizon 0-10 cm	1.418 ± 0.505[b]	1.276 ± 0.355	0.907 ± 0.390	0.015 ± 0.307	0.138
Total	0.496 ± 1.479	4.588 ± 1.943	4.251 ± 1.639	0.417 ± 0.797	0.075

Note: Forest Floor mean is the average of two 14 day periods; A-horizon mean is for one 14 day period.

[a]Forest floor Middle position n= 12, not 9 like other slope positions

[b]A- horizon Crest position n = 8, not 9 like other slope positions

Table 4-8. Rate of net N-mineralization (by volume; mean ± SE) with two-way ANOVA p-values for comparison of slope positions.

	Crest	Upper	Middle	Toe	p-value
		mg m^{-2} 14d^{-1}			
Forest Floor	18.2 ± 67.6	81.9 ± 37.0	100.8 ± 31.8[a]	7.0 ± 115.6	0.736
A-horizon 0-10 cm	183.3 ± 61.1[b]	119.9 ± 37.0	122.3 ± 45.3	70.91 ± 51.6	0.311

Note: Forest Floor mean is the average of two 14 day periods; A-horizon mean is for one 14 day period.

[a]Forest floor Middle position n= 12, not 9 like other slope positions

[b]A- horizon Crest position n = 8, not 9 like other slope positions

Table 4-9. NO_3-N/NH_4-N ratio for forest floor and A-horizons (mean ± SE).

	Crest	Upper	Middle	Toe	p-value
Forest Floor	0.05 ± 0.05	0.01 ± 0.01	0.01 ± 0.08[a]	-0.01 ± 0.02	0.842
A-horizon 0-10 cm	1.99 ± 1.97[b]	-0.35 ± 0.24	-0.13 ± 0.09	-0.10 ± 0.23	0.387

Note: Negative values occur if net N-immobilization occurred in either NO_3 or NH_4, but not both.

[a]Forest floor Middle position n= 12, not 9 like other slope positions

[b]A- horizon Crest position n = 8, not 9 like other slope positions

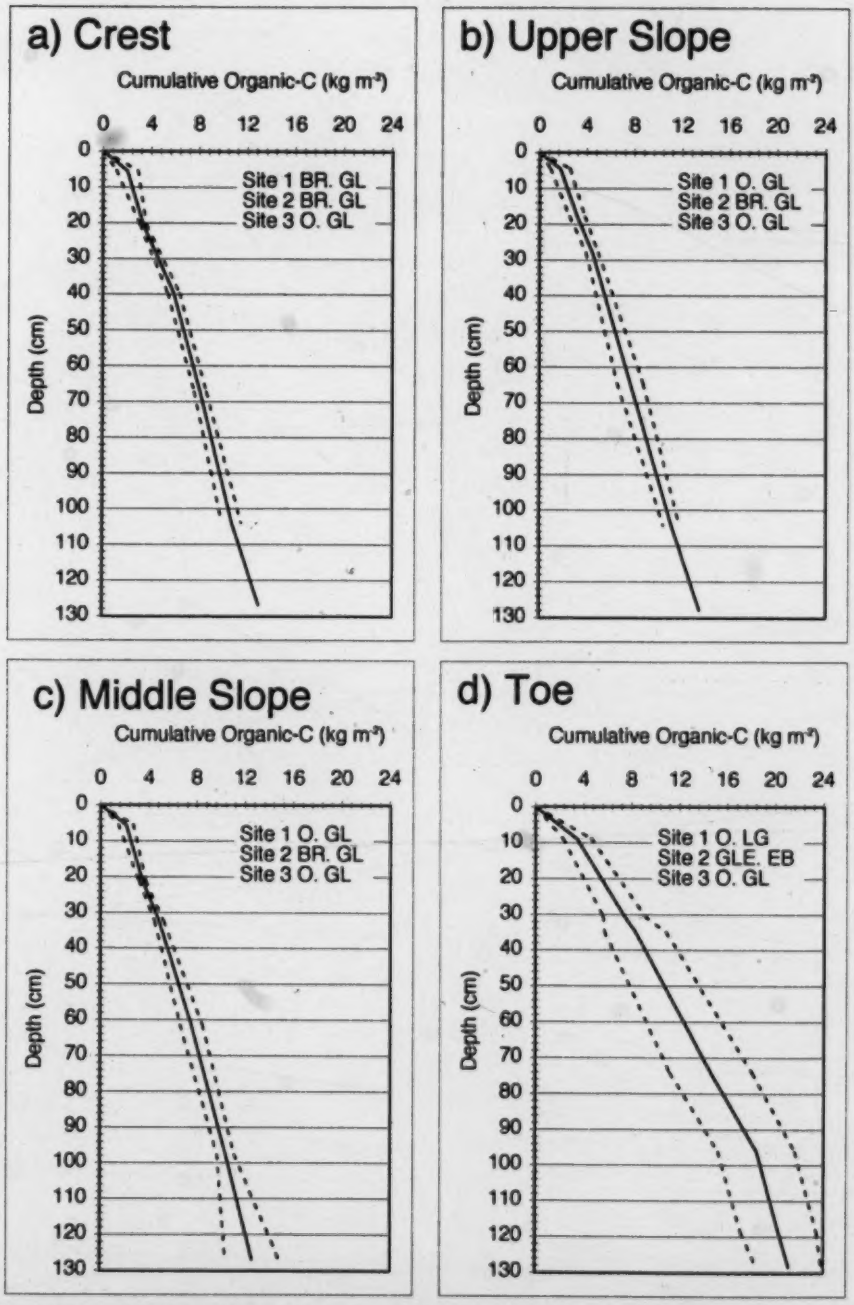

Figure 4-1. Cumulative organic-C (mean with 95% confidence limits) by depth within soil profiles for each slope position. Orthic Gray Luvisol (O. GL) is the dominant soil taxonomic class, followed by Brunisolic Gray Luvisol (BR. GL), Orthic Luvic Gleysol (O. LG), and Gleyed Eluviated Eutric Brunisol (GLE. EB).

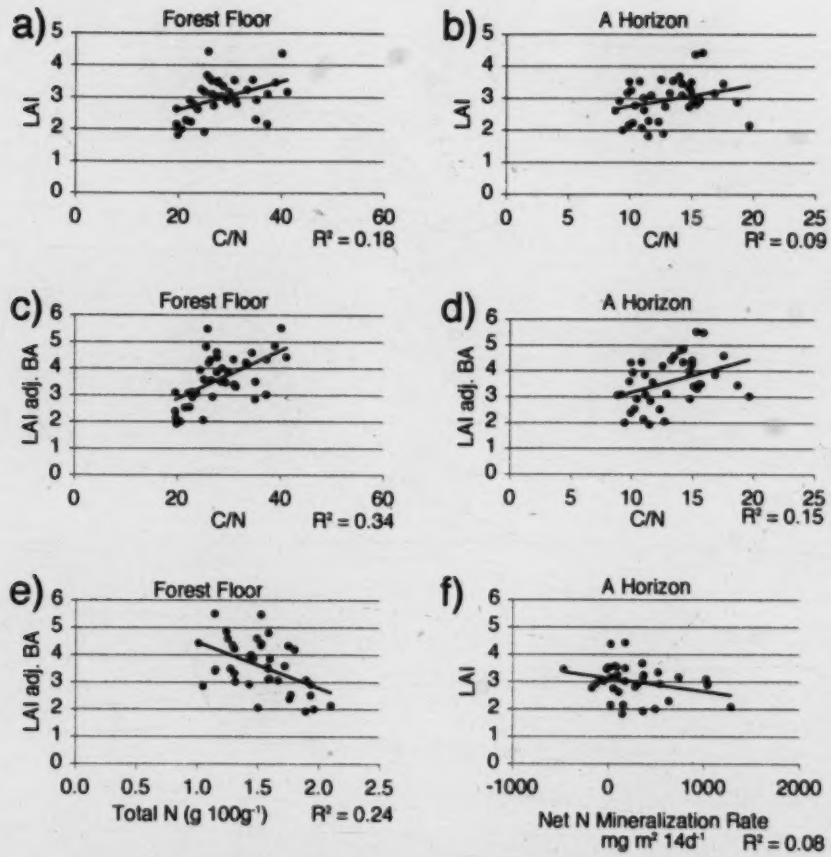

Figure 4-2. Ecological response variables regressed upon soil N parameters: Leaf area index (m^2 m^{-2}) regressed on a) forest floor C/N ($p = 0.007$), and b) A-horizon C/N ($p = 0.074$). Leaf area index adjusted for percent coniferous component (LAI adj. BA; m^2 m^{-2}) regressed on c) forest floor C/N ($p = 0.000$), d) A-horizon C/N ($p = 0.016$), and e) forest floor total N g $100g^{-1}$ ($p = 0.001$). Leaf area index regressed on f) A-horizon rate of net N-mineralization by volume ($p = 0.098$).

4.6 Literature cited

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. Res. Br. Agric. Canada, Minister of Supply and Services Canada, Ottawa. Publ. No. 1646. 164 pp.

Amponsah, G. I. 1998. Forest soil characteristics and variability under teak (*Tectona grandis* Linn. F) plantations and national forests in Ashanti region, Ghana. Unpubl. M. Sc. thesis. Lakehead Univ., Thunder Bay, Ontario. 88 pp.

Beckingham, J. D., I. G. W. Corns, and J. H. Archibald. 1996. Field guide to ecosites of west-central Alberta. Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent., Edmonton. Special Rept. 9.

Berg, B., M. P. Berg, P. Bottner, E. Box, A. Berymeyer, R. Calvo de Anta, M. Couteaux, A. Escudero, A. Gallardo, W. Kratz, M. Madeira, E. Malkonen, C. McClaugherty, V. Meentemeyer, F. Munoz, P. Piussi, J. Remacle, and A. Virzo de Santo. 1993. Litter mass loss rates in pine forests of Europe and Eastern United States: some relationships with climate and litter quality. Biogeochemistry **20**: 127-159.

Bergeron, Y., and J. Brisson. 1990. Fire regime in red pine stands at the northern limit of the species' range. Ecology **71**: 1352-1364.

Blyth, J. F., and D. A. MacLeod. 1978. The significance of soil variability for forest soil studies in north-east Scotland. J. Soil Sci. **29**: 419 - 430.

Brady, N. C. 1990. The nature and properties of soils. 10th. Collier Macmillian Pub., London. 621 pp.

Cameron, D. R., M. A. Nyborg, J. A. Toogood, and D. H. Laverty. 1971. Accuracy of field sampling for soil tests. Can. J. Soil Sci. **51**: 165 - 175.

Chen, J. M. 1996. Optically-based methods for measuring seasonal variation of leaf area index in boreal conifer stands. Agric. For. Meteorol. **80**: 135 - 163.

Culley, J. L. B. 1993. Density and compressibility. Ch. 50. pp. 529 - 539. *In* Soil sampling and methods of analysis. Carter, M. R. Ed. Lewis, London. 1995. 823 pp.

Desponts, M., and S. Payette. 1992. Recent dynamics of jack pine at its northern distribution limit in northern Quebec. Can. J. Botany **70**: 1157-1167.

Dow Customer Service. 1998. Thickness of Heavy Duty Ziploc Freezer Bags. Telephone, Monday, July 20, 1998.

Dyrness, C. T., and R. A. Norum. 1983. The effect of experimental fires on black spruce forest floors in interior Alaska. Can. J. For. Res. **13**: 879-893.

Dyrness, C. T., K. Van Cleve, and J. D. Levison. 1989. The effect of wildfire on soil chemistry in four forest types in interior Alaska. Can. J. For. Res. **19**: 1389-1396.

Environment Canada. 1998. Canadian Climate Normals 1961 to 1990. www.cmc.ec.gc.ca/climate/normals/E_AL_NDX.HTM. Accessed: 15 November, 2000. Environment Canada.

Fisher, R. F. 1995. Soil organic matter: clue or conundrum? pp. 1 - 11. *In* Carbon forms and functions in forest soils. McFee, W. W. and M. J. Kelly Eds. Soil Science Society of America Inc., Madison. 1995. 594 pp.

Gower, S., and J. M. Norman. 1991. Rapid estimation of leaf area index in conifer and broad-leaf plantations. Ecology **72**: 1896 - 1900.

Hall, R. J. 1998a. LAI measurement in mixedwood forest stands. Email, Thursday, June 11, 1998, 1:14 PM.

Hall, R. J. 1998b. Special lecture - leaf area index ver. 1.1. Nat. Resour. Can., Can. For. Serv., North. For. Cent. Lecture, August 1998.

Harden, J. W., S. E. Trumbore, B. J. Stocks, A. Hirsch, S. T. Gower, O. N. KP, and E. S. Kasischke. 2000. The role of fire in the boreal carbon budget. Glob. Chang. Biol. **1**: 174-184.

Hobbie, S. E., J. P. Schimel, S. E. Trumbore, and J. R. Randerson. 2000. Controls over carbon storage and turnover in high-latitude soils. Glob. Chang. Biol. **1**: 196-210.

Huang, W. Z., and J. J. Schoenau. 1996. Forms, amounts and distribution of carbon, nitrogen, phosphorus and sulfur in a boreal aspen forest soil. Can. J. Soil Sci. **76**: 373-385.

Johnson, D. W. 1992. Effects of forest management on soil carbon storage. Plant and Soil **64**: 83-120.

Johnson, D. W., and P. S. Curtis. 2001. Effects of forest management on soil C and N storage: meta analysis. For. Ecol. Manage. **140**: 227-238.

Johnson, R. A., and G. K. Bhattacharyya. 1992. Statistics: principles and methods. 2nd. John Wiley & Sons, New York. 686 pp.

Kimmins, J. P. 1987. Forest ecology. Collier Macmillian Pub., London. 531 pp.

Li-Cor Inc. n.d. The LAI-2000 Plant Canopy Analyzer. Li-Cor Inc., Lincoln.

MacDonald, B. G. 1995. The case for boreal mixedwood management: an Ontario perspective. For. Chron. **71**: 725 - 734.

Macyk, T. C., S. Pawluk, and J. D. Lindsay. 1978. Relief and microclimate as related to soil properties. Can. J. Soil Sci. **58**: 421 - 438.

Mann, D. H., and L. J. Plug. 1999. Vegetation and soil development at an upland taiga site, Alaska. Ecoscience **6**: 272-285.

Maynard, D. G., and Y. P. Kalra. 1993. Nitrate and exchangeable ammonium nitrogen. Ch. 4. pp. 25 - 38. *In* Soil sampling and methods of analysis. Carter, M. R. Ed. Lewis, London. 1995. 823 pp.

McClave, J. T., and F. H. Dietrich II. 1991. Statistics. Collier MacMillian Canada, Toronto. 928 pp.

McColl, J. G., and N. Gressel. 1995. Characterization and modern methods of analysis. pp. 13 - 32. *In* Carbon forms and functions in forest soils. McFee, W. W. and M. J. Kelly Eds. Soil Science Society of America inc., Madison. 1995. 594 pp.

McLaren, R. G., and K. C. Cameron. 1997. Soil Science. Oxford University Press, New York. 304 pp.

Meentemeyer, V. 1978. Macroclimate and lignin control of litter decomposition rates. Ecology **59**: 465-472.

Meentemeyer, V., and B. Berg. 1986. Regional variation in rate of mass loss of *Pinus sylvestris* needle litter in Swedish pine forests as influenced by climate and litter quality. Scand. J. For. Res. **1**: 167-180.

Metz, L. J., C. G. Wells, and B. F. Swindel. 1966. Sampling soil and foliage in a pine plantation. Soil Sci. Soc. Am. Proc. **30**: 397-399.

Microsoft. 1998. Microsoft Excel 98 Macintosh Edition.

Moore, T. R., J. A. Trofymow, B. Taylor, C. Prescott, C. Camire, L. Duschene, J. Fyles, L. Kozak, M. Kranabetter, I. Morrison, M. Siltanen, S. Smith, B. Titus, S. Visser, R. Wein, and S. Zoltai. 1999. Litter decomposition rates in Canadian forests. Glob. Chang. Biol. **5**: 75-82.

Nalder, I. A., and R. W. Wein. 1999. Long-term forest floor carbon dynamics after fire in upland boreal forests of western Canada. Glob biogeochem cycles **13**: 951-968.

Offord, J. L. 1999. Nitrogen mineralization patterns in boreal forest soils. Unpubl. M. Sc. thesis. Univ. of Alberta, Edmonton, Alberta. 183 pp.

Paul, E. A., and F. E. Clark. 1996. Soil microbiology and biochemistry. 2nd. Academic Press, Toronto. 340 pp.

Soil Science Society of America. 1998a. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 10 April, 2001. Soil Science Society of America.

Soil Science Society of America. 1998b. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 15 November, 2000. Soil Science Society of America.

Soil Survey Staff. 1998. Keys to soil taxonomy. 8th. U.S. Dept. of Agric., Nat. Resour. Conserv. Serv., Washington, D.C. 326 pp.

SPSS. 1995. SPSS 6.1.1 for Power Macintosh.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics. 2nd. McGraw-Hill, New York. 633 pp.

Taylor, B. R., C. E. Prescott, W. J. F. Parsons, and D. Parkinson. 1991. Substrate control of litter decomposition in four Rocky Mountain coniferous forests. Can. J. Botany **69**: 2242-2250.

Trettin, C. C., D. W. Johnson, and D. E. Todd Jr. 1999. Forest nutrient and carbon pools at Walker Branch Watershed: changes during a 21-year period. Soil Sci. Soc. Am. J. **63**: 1436 - 1448.

Twardy, A. G., and I. G. W. Corns. 1980. Soil survey and interpretations of the Wapiti map area, Alberta. Alberta Res. Coun., Edmonton, Alberta, 134 pp.

Van Cleve, K., F. S. Chapin, III, C. T. Dyrness, and L. A. Viereck. 1991. Element cycling in taiga forests: state-factor control. BioScience **41**: 78-88.

Van Cleve, K., and R. F. Powers. 1995. Soil carbon, soil formation and ecosystem development. pp. 155 - 200. *In* Carbon forms and functions in forest soils. McFee, W. W. and M. J. Kelly Eds. Soil Science Society of America Inc., Madison. 1995. 594 pp.

Van Veen, J. A., J. N. Ladd, and M. J. Frissel. 1984. Modeling C and N turnover through the microbial biomass in soil. Plant and Soil **76**: 257 - 274.

Waring, R. H., and W. H. Schlesinger. 1985. Forest ecosystem concepts and management. Academic Press, London. 340 pp.

Chapter 5

Modeling of Soil-Site Net Forest Productivity along Toposequences of White Spruce - Aspen (*Picea glauca – Populus tremuloides*) Mixedwood Communities in West-Central Alberta

5.1 Introduction

In this study one of the primary goals of examining soil properties is to understand their relationships with plant communities. The reason is to evaluate forest-site quality, which is the ability of an area of land to grow trees (MacLeod and Blyth, 1955; Carmean, 1996a). Soil-plant relationship research has been referred to as soil-site evaluation. Carmean (1975) has an excellent review of many soil-site evaluation studies in the United States including boreal forest species such as eastern and western pines (*Pinus* spp.), spruces (*Picea* spp.), as well as deciduous species (*Populus* spp. and *Betula* spp.). However, site index as an expression of site quality is not appropriate for mixedwood forests, and this forest type occupies about 25% of the boreal forest area in Alberta (Canadian Forest Service, 2000). Site index is not appropriate because of the variation in species composition on a site, and the very different growth habits of species within the plant community (MacLeod and Blyth, 1955). The growth history of the stand and individual trees in the community is not normally available, especially in virgin forests. Without detailed records the duration and intensity of plant growth stress is not known, and an unknown stand history defeats the accurate determination of the ability of a site to produce maximum tree height growth at any given age.

Research into site-index modeling has continued, but modeling can be expanded to incorporate more ecologically-based dependent variables as opposed to using only tree height at a given stand age (SI). Ecological-based proxies of net primary production (NPP) such as effective leaf area can be used to model the more complicated relationships of the mixedwood forests. Net primary productivity is well correlated to maximum foliage (Webb *et al.*, 1983; Waring and Schlesinger, 1985).

Net primary productivity (NPP) is the rate of accumulation of plant biomass (assimilated C) after consideration of losses due to consumption and respiration, and it is a fundamental estimate of plant community productivity (Waring and Schlesinger, 1985; Kimmins, 1987; Soil Science Society of America, 1998*a*). It accounts for the utilization of site resources by the entire community, instead of just

the crop species. This is important in determining the potential of a site to grow trees, even if site resources are mostly consumed by non-economic species in the association.

Leaf area (LA) is key in determining net primary productivity. Leaves are the primary sites for capture of solar radiation. In this way the amount of leaf area, measured at the stage of maximum foliar carrying capacity, is an excellent proxy for NPP (Gholz, 1982; Webb *et al.*, 1983; Waring and Schlesinger, 1985; Kimmins, 1996). A measure of leaf area, leaf area index (LAI; is the projected leaf area in m^2 per ground area m^2), has explained 85% to 89% of aboveground NPP of forests of the mid-western United States (Fassnacht and Gower, 1997). In north-central Wisconsin forests containing boreal species such as jack pine (*Pinus banksiana* Lamb.), paper birch (*Betula papyrifera* Marsh.), trembling aspen (*Populus tremuloides* Michx.), as well as other hardwood species LAI accounted for 62% to 80% (R^2) of the variation in aboveground net primary productivity (Fassnacht and Gower, 1997).

5.1.1 Selection of soil properties

Multiple regression equations for soil-site evaluation explain, in mathematical terms, the relationship between the capacity of a site for growing trees, and two or more soil property variables. In the boreal forest many soil properties have been used to predict site index. Typically the influential soil variables pertain to the thickness of soil horizons (Carmean, 1975; Barnes *et al.*, 1998), *e.g.*, soil depth, depth of the A-horizon, depth to the root restricting layer, depth to bedrock, depth to mottling, *etc.* (Table 5-1). These soil properties actually suggest the importance of the volume of soil from which a plant can draw essential resources for growth (Barnes *et al.*, 1998).

Other soil properties that have been influential in past studies describe the quality of the soil for providing essential resources. However in some cases selected soil variables are merely correlated with site-quality; they have no "cause and effect" relationship. In other words, fundamentals of plant biology describe soil as having an influence upon plant growth but the mathematical relationships may not always have firm biological connection. For example slope position may appear to have a significant cause-effect relationship with plant growth. Slope position was correlated to soil properties such as soil temperature and soil water (Macyk *et al.*, 1978). Slope position is a conditioning factor interacting with other conditioning factors that influence operative soil properties such as soil water (Klijn and Witte, 1999). It is the operative soil property that is related biologically to plant growth. In another example, a soil-site evaluation model by La Valley (1991) uses colour of clay (gray or red) designated 1 and 2 respectively. These clay colours were "considered to have little biological foundation"(La Valley, 1991). Lack of

"cause and effect" relationships in soil-plant relationship research does not help suggest effective measures for modification of soil properties of a site to improve, maintain, or just monitor soil-quality of plant communities being used in forestry. In the interest of furthering our knowledge about soil-plant relationships at specific small-scales (site) locations it is desirable to develop models in which soil properties have "cause and effect" relationships with site-quality.

Some soil-site evaluation equations rely on qualitative soil variables. Qualitative variables are subjective descriptions of soil properties and may lead to errors due to differences in interpretation of the category in which they belong. Some examples of qualitative variables are shown in Table 5-1; *e.g.*, the colour of clay (gray or red) and drainage class. Deciding on the proper class may be affected by individual interpretation of the guidelines defining a class. In the case of both colour of clay and hue of the C-horizon there is a subjective selection between the similarity of soil colour and the chart colour. One trait that is preferable for soil property variables is that they not be subjectively assessed and categorized. Use of such variables is possible, but may decrease the accuracy of the predicted value.

The most important soil properties affecting leaf area in the boreal forest are soil water/drainage and temperature (Corns, 1978; Kimmins, 1996). Drought conditions influence the availability of nutrients by decreasing decomposition and restricting mass flow of nutrient ions to root surfaces (Fassnacht and Gower, 1997). Soil N is also expected to be an influential soil property growth of plant communities in this study. Soil N is the critically limited nutrient in the boreal forest due to poor nutrient cycling according to several studies (Huntington *et al.*, 1988; Fassnacht and Gower, 1997; Knoepp and Swank, 1997). Nitrogen is immobilized in organic matter.

Unfortunately, the natural spatial variability of forest soil properties creates some difficulty in the study of tree growth and soil property relationships. The most desirable soil properties describing tree growth will also have the least amount of spatial variation (Blyth and MacLeod, 1978) especially at a scale similar to that of the plant community productivity. This in effect reduces the experimental error in the regression analysis by dealing with the inherent variability of soil properties. Reduction of experimental error improves the power of statistical tests and reduces the size of confidence intervals (Steel and Torrie, 1980).

How a site is defined is also critical to the effectiveness of the soil-site study (Carmean, 1975) and to reducing experimental error. Stratification of sites or refinement of the experimental technique can reduce experimental error when there is a lack of uniformity in the experimental units (Steel and Torrie, 1980). For example, in soil-site evaluation models species growth information was stratified by soil parent

material, *i.e.*, sorting data into groups with similar landscape processes to reduce variation of soil properties (Carmean, 1996b). The break down of characteristic species growth with respect to parent material had an impact on the amount of variation described in these soil-site evaluation equations (Table 5-1). Table 5-1 shows the amount of variation explained (R^2) by the six soil-site evaluation equations, stratified by parent material type (morainal, glaciofluvial, and lacustrine), for both plantation white spruce and natural trembling aspen stands. In this study to develop soil-plant relationship models, landscape-level factors such as regional climate and surficial geology were held constant by limiting the study area to a relatively small area.

The primary objective of this study was to use multiple regression analysis to model relationships between selected soil properties and leaf-area ecological response variables. Effective leaf area index (LAI) measured by an Li-Cor LAI 2000 (Li-Cor Inc., n.d.), and LAI adjusted by percentage species basal area to account for changing deciduous-coniferous composition along examined toposequences were the proxies for net primary productivity. The explanatory variables were soil properties and interactions of those soil properties.

5.2 Materials and methods

5.2.1 Study area

The study area (54°40'N, 118°13'W, 787 ± 26 m ASL) was approximately 70 km southeast of Grande Prairie, Alberta. It falls within the Lower Foothills Natural Sub-region (Beckingham *et al.*, 1996), and lies on the border of the Wapiti Plains and the Alberta Benchland Plateau physiographic region of the Interior Plains (Twardy and Corns, 1980). This area has rolling relief (Agriculture Canada Expert Committee on Soil Survey, 1987), and is comprised of glaciolacustrine, till and glaciofluvial materials deposited during the late Pleistocene epoch (Twardy and Corns, 1980).

The soils typical of the study area are Gray Luvisols (Twardy and Corns, 1980; Agriculture Canada Expert Committee on Soil Survey, 1987), or Haplocryalfs (Soil Survey Staff, 1998). The soils of this study conform to the specifications of the Donnelly soil group. The Donnelly soil group is derived from glaciolacustrine or lacustrotill deposits (Twardy and Corns, 1980). The Donnelly soil group includes Orthic Gray Luvisols (O. GL) and Orthic Luvic Gleysols (O. LG) in the lower slope positions "where groundwater discharge and surface waters tend to accumulate" (Twardy and Corns, 1980).

Regional climate of the study area is continental, *i.e.*, long, cold winters and mild summers (Twardy and Corns, 1980). The climate of the Lower Foothills Natural Sub-region is characterized by a mean

annual temperature of 3.0 °C, and total annual precipitation of 464 mm (Beckingham *et al.*, 1996). Grande Prairie, Alberta is the nearest full-time weather station to the study area (Grande Prairie A, Station Id#: 3072920, 55°11' N, 118°53' W, 666 m ASL). The mean annual temperature for Grande Prairie is 1.6 °C and the total annual precipitation was 450.2 mm (308.6 mm rainfall) based on 30 years of data (Environment Canada, 1998).

The study area is classified as boreal mixedwood, which is characteristic of the Lower Foothills Natural Sub-region (Beckingham *et al.*, 1996). Predominant vegetation at the top slope position is typically white spruce (*Picea glauca* (Moench) Voss) and trembling aspen (*Populus tremuloides* Michx.) with an understory dominated by the shrub green alder (*Alnus crispa* (Ait.) Pursh) and bracted honeysuckle (*Lonicera involucrata* (Richards.) Banks). Toe slope positions are dominantly white spruce and black spruce (*Picea mariana* (Mill.) BSP) with Labrador tea (*Ledum groenlandicum* Oeder), feather moss (generally *Ptilium*, *Pleurozium* and *Hylocomium* spp.) or *Sphagnum* ground cover.

5.2.2 Sampling design

To achieve the objective of this study, prospective toposequences were sampled within the study area. A toposequence was defined as a consecutive series of topographic positions (Beckingham *et al.*, 1996). Toposequences were selected to meet several criteria. First, they were examined to ensure there were no recent disturbances, such as human activity, disease, insect damage/defoliation, or fire since stand origin. Second, the forest was to be dominantly spruce and aspen mixedwood. Third, the stands were to be uniform in age along a given toposequence. Finally, trees along toposequences should not be degrading as a result of old age, but near to the optimum rotation age with a full canopy.

Three toposequences were used as study sites: Site 1 was 350 m long and varied between 765 m and 789 m above sea level (ASL) (24 m relief). Site 2 was 130 m long and its elevation varied from 812 m to 820 m ASL (8 m relief). Site 3 was 290 m in length; and the top and bottom slope elevations were 762 m to 774 m (12 m relief).

Toposequence sites were subdivided into transects (3), transect positions, and plots. Three nearly parallel transects separated by 15 m to 30m were established for replicated sampling of slope position within a toposequence site. Plots were the sampling locations along each transect within a toposequence site (Figure 2-5). In the terrain of this study the lower slope position was not sampled on all toposequence sites as a result of the proximity of adjacent plots. Therefore, only the crest, upper, middle and toe slope positions were used to compare toposequence sites. In all comparisons, the middle slope positions had an

unbalanced sample size because Site 1 had two transect positions that met the form criteria of middle slope.

Also, following completion of soil morphological description and sampling, specific mineral soil horizons were aggregated into one of three horizon categories based on genetic features (Agriculture Canada Expert Committee on Soil Survey, 1987). The aggregate categories were as follows: 1) A-horizon, including all A-horizon variations (Ah, Ahe, Ae, *etc.*) occurring in a soil profile, the AB transition horizon if present, and a Bm or a Bf developed in the A-horizon zone of polygenetic soil profiles, *e.g.*, the Bm in a Brunisolic Gray Luvisol (BR. GL), and the Bf in a Podzolic Gray Luvisol (PZ. GL); 2) B-horizon including variations of the horizon (Bt_1, Bt_2, Btnj, Bg, *etc.*) occurring in the soil profile and the BC transition horizon if present; 3) C-horizon, containing all variations of the horizon *e.g.*, Ck, Cca and Cg *etc.*

5.2.3 Ecological response variables of forest mixedwood communities

Stand data were collected from plots (sites). Stand-level variables such as effective leaf area index[1] (LAI), basal area (BA), tree density and age were used to assess similarity of toposequence sites. Basal area, mean annual increment of BA and LAI were also used as estimates of net primary productivity 1.3 m above the forest floor.

Net primary productivity is a fundamental measure of forest-site productivity (Soil Science Society of America, 1998). It is the rate of plant biomass accumulation after losses due to consumption and respiration. Productivity is the rate of accumulation of a specified material (Kimmins, 1987), and in this study it refers more specifically to tree and shrub net biomass by excluding biomass under 1.3 m height (breast height). Effective leaf area index, basal area, and basal area increment will be referred to as ecological response variables because they are surrogates for net primary production in response to site conditions.

Leaf area index as a proxy of the site net primary productivity, was measured by a LAI-2000 Plant Canopy Analyzer (Li-Cor Inc., Lincoln, Nebraska). Within plot measurements were taken from nine locations (8 at every 45° azimuth along the plot perimeter plus one at plot center) to estimate effective

---

[1] Effective leaf area index (LAI) value as measured by the Li-Cor 2000 Plant Canopy Analyzer (Gower and Norman, 1991; Chen, 1996; Hall, 1998b; Li-Cor Inc., n.d.). It may be abbreviated eLAI, LAI_e, or L_e in other literature.

LAI per 100 m^2 square plot. Measurements were taken only when continuous and uniform cloud cover occurred during the period from 25 to 31 August 1998 between 8 AM and 4 PM, immediately prior to the first evidence of leaf abscission. Continuous and uniform cloud cover during the day provided uniform light conditions for measurements. Light intensity readings required about 10 min per plot: about four minutes for diffuse light (Q_d) within plot (n = 9), and about six minutes to traverse between the plot and an area with no overhead cover (Q_o).

Leaf area index was adjusted by basal area (LAI adj. BA) for species composition (*i.e.*, proportion of coniferous component) of the sample site (plot; eq. 3-1). The adjustment was necessary since the Li-Cor LAI-2000 instrument underestimates LAI by 35 to 40% (Gower and Norman, 1991; Hall, 1998a; Hall, 1998b).

The forest stand parameters of basal area, tree height, tree diameter outside bark (dbhob), sapwood area, and age at 1.3 m above ground level (breast height) were collected from sample trees selected by the point sample method (Husch *et al.*, 1982). These data sets were collected between 27th August and 14th September 1998. Only plot centers nearest to the midpoints of the crest, lower slope, toe and depression positions of the slope were sampled to prevent repeated measurement of large sample trees from adjacent within-transect positions. Tree age was estimated from tree cores extracted at 1.3 m.

5.2.4 Soil properties

Soils were characterized by a pedon description and from horizon samples at each plot along the center transect (Agriculture Canada Expert Committee on Soil Survey, 1987). Spatial intensity of soil sampling varied by horizon depth according to the general knowledge of horizontal and vertical spatial variability of soil properties (Metz *et al.*, 1966; Cameron *et al.*, 1971; Blyth and MacLeod, 1978; Amponsah, 1998). There were 62 soil property variables derived from a core set of soil properties:

1) Horizon thickness
2) Field pH in water
3) Bulk density
4) Percentage organic-C and N
5) *In-situ* Rate of net N-mineralization
6) Particle size distribution
7) Ambient soil water contents for the,
   a) forest floor and A-horizon - 29 to 31 July 1998
   b) forest floor - 12 to 15 August 1998 and
   c) B-horizon - 7 to 13 October 1998.

Refer to Chapters 3 and 4 for the results of the soil properties according to toposequence sites, slope positions and soil horizons.

5.2.5 Statistical analyses

Multiple linear regression analysis (Steel and Torrie, 1980; McClave and Dietrich II, 1991; Johnson and Bhattacharyya, 1992; Ryan, 1997) was performed using SPSS 6.1.1 (SPSS, 1995). Seven steps were taken to determine the soil property variables (independent or explanatory variables) most influential to the prediction of LAI, and LAI adjusted for the coniferous component of the stand by basal area (LAI adj. BA, calculated by eq. 3-1; dependent variables). The steps were to:

1) Define key objectives;
2) Screen for the variables that are most sensitive to changes in LAI and LAI adj. BA;
3) Graphically examine trends in matrix plots;
4) Make transformations to soil properties (if necessary) to improve the amount of explained variation of each leaf-area ecological response variable;
5) Fit a model that best explains the variation in the leaf-area ecological response variables using all of the selected soil variables;
6) Use various regression methods (forward, backward and stepwise) to assist in selection of the best subsets of the selected soil variables; and
7) Analyze the best subsets of variables to determine the most concise model that explains the greatest amount of variation in the leaf-area ecological response variables.

The key objective was to use multiple regression analysis to model soil-plant productivity relationships (step 1). Additional constraints to development of the mathematical model were selected soil property variables should be quantitative and have a biological foundation in the prediction of the local leaf-area ecological response variables.

To screen the 62 soil variables a Pearson product moment coefficient of correlation matrix (Steel and Torrie, 1980; McClave and Dietrich II, 1991) was generated using Microsoft Excel (Microsoft, 1998). The correlation matrix indicated soil variables highly correlated to other soil variables, and not highly correlated to the dependent variables (step 2). After the initial screening of variables only 30 appeared to be correlated to the leaf-area ecological response variables. Further exploration of these 30 selected variables involved examining trends using matrix-scatter plots generated by SPSS 6.1.1. (step 3). These plots indicated that only 13 of the 30 variables showed trends, and three of those required transformations. In addition the matrix-scatter plots indicated that two values appeared to be outliers. These two values were greater than two standard deviations from the mean implying they were not in the

range of 95% of the data (McClave and Dietrich II, 1991). Since these two values were in the tail region of the distribution there were removed from the data set.

After removal of the two outliers that were outside of the expected range of 95% of the data, transformations were made to the three non-linear variables (step 4). Transformations were made for forest floor total N (ff_percN), forest floor C/N ratio (ff_cn), and the first B-horizon total N (b1_percN). In each case the most appropriate transformation was the inclusion of a quadratic term in the model. The coefficient of the soil property (β_1) shifts the parabolic trend right to left, and the coefficient of the quadratic term of the soil property (β_2) indicates the rate of curvature (McClave and Dietrich II, 1991).

Another correlation matrix was generated to reassess and list soil property variables sensitive to the leaf-area ecological response variables. After this step, eight soil variables appeared to best describe the variation for both leaf-area ecological response variables. The model with all of the soil properties selected up to this step were used to fit a 'rich model'. The 'rich model' had eight soil property variables (step 5). Stepwise, backward and forward regression methods were used to select the best subsets of explanatory variables (step 6). Four soil property variables described the greatest amount of variation in leaf-area ecological response variables (step 7). The observed values of leaf-area ecological response variables were plotted against the predicted values with the 95% prediction interval (Figure 5-1 a,b) as an indication of the sensitivity of the prediction equations.

5.3 Results and discussion

Only four of the eight soil variables of the rich model described the variation in the leaf-area ecological response data (Table 5-2). The model that best described the variation in data for LAI (eq. 5-1) had an R^2 of 0.62 (Table 5-3), and the best model for LAIBA (eq. 5-2) had R^2 of 0.70 (Table 5-4). The results of the two leaf-area ecological response variable models are shown in Figure 5-1.

[5-1] $$LAI = \beta_0 + \beta_1(ff_percN) + \beta_2(ff_percN)^2 + \beta_3(ff_db) + \beta_4(b_silt) + \beta_5(b_pwp_h)$$

[5-2] $$LAIBA = \beta_0 + \beta_1(ff_percN) + \beta_2(ff_percN)^2 + \beta_3(ff_db) + \beta_4(b_silt) + \beta_5(b_pwp_h)$$

In order to maintain the optimum precision for the estimation of net primary productivity in this study, one needs to consider the inference space of these equations (eq. 5-1 and 5-2) including: the Iosegun Plain physiographic region in areas of luvisolic soils (no regional groundwater discharge) and

rolling terrain. The equations apply to an area of one-fifth to four-fifths spruce to aspen vegetation. These mixedwood communities should have an average age of 92 ± 12 years and full crown closure. In this study a full crown was considered to be achieved by trees and shrubs once they were using site resources to their full potential, and not competing for light resources with forbs, grasses and the moss layer. Proxy measurements of net forest productivity were taken at breast height (1.3 m above the ground surface) as an estimate of when crowns of trees and shrubs surpassed those of forbs, grasses and the moss layers.

In addition, to maintain the optimum precision of estimating net primary productivity, the equations (eq. 5-1 and 5-2) apply to mixedwood stands that show no signs of natural disturbance since stand origin. In ecosystems, such as those described above, the value of the leaf-area ecological response variable prediction equations is expected to describe 62% and 70% of the variation of LAI and LAI adj. BA respectively.

In past studies of soil-site evaluation the multiple regression equations described between 65% and 85% of the variation in the dependant variable (Carmean, 1975). In 1984, soil-site index regressions for the Wapiti Plains area were developed (Corns, 1978). The variation in site index described by soil properties was 24 to 49% for pine, 53 to 58% for white spruce, 88 to 98% for black spruce and 74 to 94% for aspen. More recently La Valley (1991) produced soil-site evaluation models for planted white spruce explaining 62% to 83% of the variation in site index (SI). Carmean (1996a) published models describing 65% to 83% of the variation in SI for jack pine (*Pinus banksiana* Lamb.), and in 1997 Fassnacht and Gower (1997) produced models explaining 66% to 76% of the variation in LAI for conifer, mixedwood, and hardwoods of north-central Wisconsin.

Soil-site equations have been able to describe more than half of the variation in the dependent variable. In this study the objective was to use multiple regression analysis to understand existing relationships of soil properties and leaf-area ecological response variables. As such, variables were selected considering why and how they influence LAI and LAI adj. BA. Only four of more than 60 soil property variables examined appeared to influence the leaf-area ecological response variables (Table 5-2).

Forest floor bulk density was included in both LAI and LAI adj. BA prediction equations (eq. 5-1 and 5-2). Forest floor bulk density was positively correlated with the deciduous basal area of the stand, and negatively correlated with water content of the mineral soil horizons. Unfortunately, the forest floor bulk density is not different ($p > 0.05$) among slope positions so the true value of forest floor as an indicator of site-quality should be considered in conjunction with our confidence in the mean values at each slope position (Table 3-7).

The concentration of forest floor N (g N (100 g soil)$^{-1}$) required a second order polynomial transformation to improve the fit with the LAI ecological response variables. This polynomial transformation may be explained by the N requirements of the deciduous and coniferous tree and their relative proportions along the toposequences. Nitrogen characteristics of the forest floor mainly reflected the species composition of the existing vegetation (Fyles and McGill, 1987). Plant uptake of NH_4^+ is more important in nutrition of coniferous than deciduous stands (Nadelhoffer *et al.*, 1984). The required N of boreal conifers was more closely correlated to net primary production than that of boreal deciduous species (Cole and Rapp, 1981). Cole and Rapp (1981) reported that boreal conifers receive nearly all of their annual N requirement for biomass production from uptake (Table 5-5). Deciduous trees only receive two-thirds of their annual N requirement for biomass production from uptake; the remainder being translocated from older tissues. Nitrogen cycling describes more of the variation in biomass production in coniferous species. This suggests that concentration of total N in the forest floor has a strong theoretical foundation in the prediction of leaf-area ecological response variables for our study area, especially conifer dominated mixedwoods.

Unfortunately, the value of the concentration of total N in the forest floor toward describing the net primary production is limited by high spatial variability interacting with a range of coniferous and deciduous stand composition. The lowest forest floor N concentration (Table 4-6) occurred at the bottom of the slope with greatest LAI and LAI adj. BA values (Table 4-6; Figure 5-1 a,b). Here the forest floor is thicker, more continuous, and more biologically active as suggested by the difference ($p \leq 0.05$) among slope positions for C/N ratios (Table 4-5). The high C/N ratios suggest there was greater competition for N between forest floor microorganisms and trees since there is more C per N available at the toe. This is supported by the trend of the rate of net N mineralization along the slope (Table 4-8), albeit without significant difference ($p > 0.05$).

In the middle slope position the forest floor total N was greater and C/N ratios lower than the toe. Leaf-area ecological response variables were near maximum at the middle slope position, and this is where coniferous-deciduous species composition was nearly equal. It appears that conifers' leaf area responded to the relative increase of total N (g 100g^{-1}). The leaf-area ecological response variables fell to the lowest point at the top of the slope where deciduous trees dominated the stand. There were very few conifers at the top of the slopes and deciduous trees do not correlate well to N uptake and requirement (Table 5-5). Therefore forest floor N concentration appears to indicate the contribution of coniferous species to leaf area index.

Since deciduous-tree biomass production is not as dependent on soil N uptake as coniferous trees (Table 5-5), the greatest amount of variation of leaf area index nearer the top of the slope may be best described by available soil water. It is accepted that the level of plant production cannot be greater than the most limiting plant-growth factor (Brady, 1990). The top of the slope had less available water in the forest floor and A-horizon during late July, and in all mineral horizons in early October (Figures 3-2 and 3-3). The latter is immediately after the May to September period. May to September is when more than half (63%) of annual precipitation occurs in the region according to the Grande Prairie, Alberta climate normal data (Figure 2-4; Environment Canada, 1998). In 1998, for Economy Tower station about 1 km north of site 1 the amount of precipitation from May to August was about 318 mm (Environment Canada, 1998). Therefore it appears that the selected soil properties associated with water content may account for the greatest amount of variation in deciduous leaf area.

It is possible that the rate of net N mineralized was not a contender as an independent variable because of the amount of spatial variation along the toposequences. In this study rate of N mineralized was greatest at upper slope positions, and this is supported by another boreal spruce ecosystem study (Munson and Timmer, 1991). However the variation in net N mineralized was too great to detect differences among slope position and toposequence sites. Therefore the rate of net N mineralized had no power to describe the variation in leaf-area ecological response variables. A study that supports the lack of difference between sites involved laboratory N incubations of organic soil and A-horizon samples. These samples were taken from two *Populus – Picea* forests stands primarily growing in Gray and Dark Gray Luvisols of central Alberta. These results also showed no differences in net N mineralized between the two sites, and among slope positions (Offord, 1999).

The silt content of the B-horizon was the third variable in the soil-site models. It was positively correlated to both leaf-area ecological response variables. B-horizon silt content may be biologically important because it influences soil aeration as opposed to water content at -33 (eq. 3-2) and -1500 kPa. (eq. 3-3), as well as cation exchange capacity (eq. 3-4) which are influenced primarily by soil particles with the greatest specific surface area (*i.e.*, the clay-size fraction).

In many instances those variables with a horizon depth component did not contribute enough to describing the variability of the dependent variable to be entered into the equations. This was unexpected considering the importance placed on the volume of soil capable of being occupied by roots, and supporting tree growth (effective soil volume). The importance of effective soil depth (volume) was stated in Barnes *et al.* (1998), and was suggested in a literature review by Carmean (1975). In this study,

the volume expression of soil effective for plant growth seemed not as important as the mass expression, except for B-horizon permanent wilting point.

The B-horizon permanent wilting point is the fourth variable in both of the leaf-area ecological response variable equations. This variable is the only horizon-volume based variable to influence the dependent variables. B-horizon permanent wilting point is negatively correlated with the leaf-area ecological response data, and may be a result of low matric potential during drought periods. For example, at a given soil water content the soil with the lowest permanent wilting point would be expected to have the most available water during dry periods. In this study, bottom slope positions have B-horizons with more available water; partly because they are in the water receiving position of the landscape, but also because they have lower clay contents and higher silt contents, which affect matric potential.

All of the influential soil property variables examined are quantitative and their relationship with plant community production appears to be founded in biology and silviculture. However, scatter plots of the observed against the predicted leaf-area ecological response variables (Figure 5-1 a,b) indicate the worth of these equations for prediction of plant community production along a toposequence. The 95% prediction intervals (Figure 5-1 a,b) indicate that these soil-site evaluation equations can only be expected to determine the difference between extreme top and bottom slope positions at best. The prediction interval accounts for the variability around the predicted value. It is similar to a confidence interval for a parameter except the prediction interval includes an additional variance component (Ryan, 1997). On our study sites the difference between maximum (top slope) and minimum (bottom slope) mean LAI and LAI adj. BA is 0.78 and 1.42 (m^2 m^{-2}) respectively. These differences are nearly as large as the 95% prediction interval. Therefore, these soil-site equations (eq. 5-1 and 5-2) indicate the local, influential soil property variables of the study sites, but their value for actual prediction is limited.

The width of the prediction limits for the soil-site equations may be reduced in future studies by using information from this study. Data in this study may be used to estimate the number of samples required to estimate local site-specific soil and ecological response variable values. Results from this study indicate that understanding spatial variation caused by landscape processes, is critical to the further development of estimates of soil-forest community productivity.

This study also suggested, by the number of forest floor independent variables in the regression models (eq. 5-1 and eq. 5-2) that the forest floor is important to forest-site productivity. It is accepted that recycling of nutrients (particularly N mineralization and immobilization) in the forest floor is a major component of boreal forest ecosystems (Huang and Schoenau, 1997). Unfortunately high spatial

variability of forest floor soil properties requires intensive sampling (Quesnel and Lavkulich, 1980), but perhaps stratification of forest floor (L, F and H horizons) can provide less variability and therefore better resolution of net N mineralized. For example, in mature mixedwood conifer stands in British Columbia less variation was found within individual organic matter layers than within the whole forest floor (Lowe, 1972). Huang and Schoenau (1996), reported similar results in an 80 year old aspen stand 80 km north of Prince Albert, Saskatchwen. In addition Huang and Schoenau (1997) found that fine root concentration occurred primarily in the H horizon (68%). Their results are similar to the observed root distribution in this study (Figure 3-5). So in the future, concentration on dealing with the inherent spatial variability of forest floor horizon soil properties may improve the precision of soil-site evaluation equations.

Better control of sources of variation that affect the width of the soil-site evaluation prediction interval are necessary. Use of soil property and ecological response variable data with minimal variability will reduce the prediction limits.

5.4 Conclusion

The explanatory variables of the leaf-area index regression models indicate the influential soil property variables in the study area. The selected explanatory soil variables were: concentration of total N in the forest floor, forest floor bulk density, B-horizon silt content, and B-horizon permanent wilting point. Each of these explanatory variables used to predict LAI and LAI adj. BA had an apparent biological link to plant community productivity.

It also became apparent that tree species composition of a site has a strong influence on the limiting variables. Forest floor total N appeared to describe leaf-area ecological response variables of the coniferous component of the stand. Forest floor bulk density enhanced the characterization of the forest floor, which presumably affected the supply of inorganic N to the coniferous component of the mixedwood stand. The B-horizon silt content and permanent wilting point appear to describe landscape soil water relationships that are beneficial to mixedwood leaf area response. The result was two models: one predicting LAI as estimated by a Li-Cor LAI-2000 instrument (eq. 5-1; Table 5-3; $R^2 = 0.62$, MSE = 0.1253, df = 31), and the other LAI adjusted (by basal area) for the proportion of coniferous species (eq. 5-2;Table 5-4; $R^2 = 0.70$, MSE = 0.2426, df = 31).

Table 5-1. Summary of soil-site evaluation studies (equations not given) for major species in boreal Ontario (Adapted from Carmean, 1994 and 1996b).

Species	R^2	SI m	SEE m	Parent Material	Major soil variables in the equation
white spruce[a]	0.66	7.4 $SI_{(bh15)}$[c]	0.73	Morainal	ln(depth to root restricting layer) & pH of the C-horizon
	0.62	8.0 $SI_{(bh15)}$[c]	0.94	Glaciofluvial	drainage class
	0.77	8.5 $SI_{(bh15)}$[c]	0.74	Lacustrine	type of clay, depth to root restricting layer, and hue of the C-horizon
trembling aspen[b]	0.63	18.8 $SI_{(bh50)}$[d]	1.32	Morainal	depth to root restricting layer & coarse fragments
	0.64	20.0 $SI_{(bh50)}$[d]	1.38	Glaciofluvial	depth to root restricting layer & drainage class
	0.65	20.6 $SI_{(bh50)}$[d]	1.46	Lacustrine	clay content in the C-horizon & depth to mottling

[a]plantations

[b]natural stands

[c]bh15 – reference age = 15 years measured at breast height, 1.3 m.

[d]bh50 – reference age = 50 years measured at breast height, 1.3 m.

Table 5-2. Leaf-area ecological response and selected soil variables for soil-site models (eq. 5-1 and 5-2).

Variable	Units	Code	Mean	SE	95% Confidence Limit Lower	Upper
		Ecological Response Variables				
LAI	$m^2\ m^{-2}$	LAI	2.8832	0.0874	2.7060	3.0604
LAI adj. BA		LAIBA	3.4735	0.1376	3.1943	3.7527
		Soil Variables				
Forest floor total N	$g\ 100g^{-1}$	ff_percN	1.5264	0.0436	1.4381	1.6147
(Forest floor total N)^2	$(g\ 100g^{-1})^2$	ffpercN2				
Forest floor bulk density	$g\ cm^{-3}$	ff_db	0.0944	0.0037	0.0870	0.1017
B-horizon silt content	$g\ 100g^{-1}$	b_silt	35.3485	1.356	32.604	38.093
B-horizon permanent wilting point	cm	b_pwp_h	13.7483	0.9581	11.8088	15.6878

Table 5-3. Soil-site model for LAI regressed on selected soil properties (eq. 5-1).

Analysis of Variance	df	Sum of Squares	Mean Square	Signif. of F
Regression	5	6.2813	1.2563	0.0000
Residual	31	3.8841	0.1253	

Multiple Regression Variable		Est. β	Est. SE β	VIF[a]	Signif. of t
Constant	β_0	-0.0368	1.7158	-	0.9830
Forest floor total N	β_1	5.3453	2.2387	106.632	0.0232
(Forest floor total N)^2	β_2	-1.8270	0.7248	107.494	0.0171
Forest floor bulk density	β_3	-10.3029	3.0426	1.398	0.0019
B-horizon silt content	β_5	0.0171	0.0074	1.114	0.0274
B-horizon PWP	β_6	-0.0368	1.7158	1.156	0.0041

[a]Variance Inflation Factor, which is a test for multicollinearity (Ryan, 1997).

Table 5-4. Soil-site model of LAI adjusted for species composition by basal area (LAI adj. BA) regressed on selected soil properties (eq. 5-2).

	Analysis of Variance			
	df	Sum of Squares	Mean Square	Signif. of F
Regression	5	17.7172	3.5435	0.0000
Residual	31	7.5212	0.2426	

	Multiple Regression				
Variable		Est. β	Est. SE β	VIF[a]	Signif. of t
Constant	β_0	0.9916	2.3877	-	0.6808
Forest floor total N	β_1	6.1206	3.1153	106.632	0.0583
(Forest floor total N)^2	β_2	-2.3468	1.0087	107.494	0.0267
Forest floor bulk density	β_3	-13.6860	4.2340	1.398	0.0029
B-horizon silt content	β_4	0.0261	0.0103	1.114	0.0161
B-horizon PWP	β_5	-0.0593	0.0149	1.156	0.0004

[a]Variance Inflation Factor, which is a test for multicollinearity (Ryan, 1997).

Table 5-5 Above ground biomass production normalized to annual uptake of nitrogen for boreal deciduous and boreal coniferous species, and coefficients of determination (R^2) for biomass production regressed on nitrogen cycling process (adapted from Cole and Rapp (1981); Tables 6.12 and 6.13).

Process	Boreal Forest Type	Biomass Production (kg ha^{-1} yr^{-1}) per unit N	% Significance between means	Coefficients of Determination (R^2)
Uptake	Deciduous	143 ± 36[a]	99	0.42
	Coniferous	194 ± 48		0.78
Requirement	Deciduous	102 ± 20	99	0.58
	Coniferous	201 ± 81		0.92
Return	Deciduous	180 ± 51	99	0.33
	Coniferous	283 ± 126		0.62

[a]mean ± SD

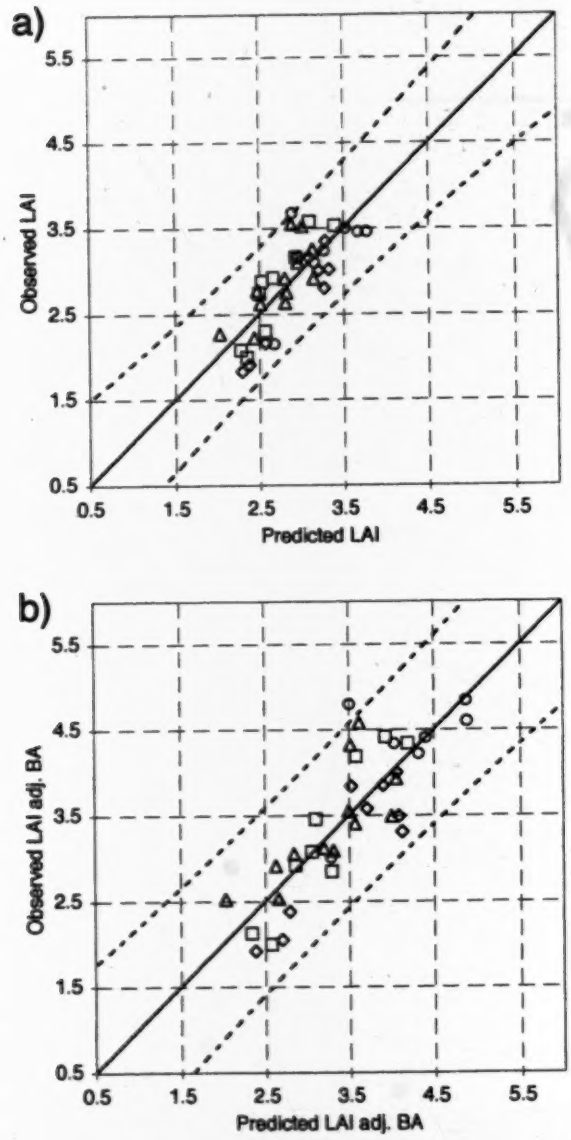

Figure 5-1. Scatter plot diagrams of the observed versus predicted a) leaf area index (LAI, $m^2 m^{-2}$; eq. 5-1) and b) leaf area index adjusted for the proportion of coniferous species in the stand, by basal area (LAI adj. BA, $m^2 m^{-2}$; eq. 5-2). The 95% prediction intervals (dashed lines) and data points for crest (square), upper (diamond), middle (triangle) and toe (circle) slope positions are included. A prediction Interval is similar to a confidence interval for a parameter except the prediction interval includes an additional variance component (Ryan, 1997). It accounts for the variability around the predicted value.

5.5 Literature cited

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. Res. Br. Agric. Canada, Minister of Supply and Services Canada, Ottawa. Publ. No. 1646. 164 pp.

Amponsah, G. I. 1998. Forest soil characteristics and variability under teak (*Tectona grandis* Linn. F) plantations and national forests in Ashanti region, Ghana. Unpubl. M. Sc. thesis. Lakehead Univ., Thunder Bay, Ontario. 88 pp.

Beckingham, J. D., I. G. W. Corns, and J. H. Archibald. 1996. Field guide to ecosites of west-central Alberta. Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent., Edmonton. Special Rept. 9.

Blyth, J. F., and D. A. MacLeod. 1978. The significance of soil variability for forest soil studies in north-east Scotland. J. Soil Sci. **29**: 419 - 430.

Brady, N. C. 1990. The nature and properties of soils. 10th. Collier Macmillian Pub., London. 621 pp.

Cameron, D. R., M. A. Nyborg, J. A. Toogood, and D. H. Laverty. 1971. Accuracy of field sampling for soil tests. Can. J. Soil Sci. **51**: 165 - 175.

Carmean, W. H. 1975. Forest site quality evaluation in the United States. Adv. Agron. **27**: 209 - 267.

Carmean, W. H. 1996a. Forest site-quality estimation using forest ecosystem classification in Northwestern Ontario. Environ. Monit. Assess. **39**: 493 - 503.

Carmean, W. H. 1996b. Site-quality evaluation, site-quality maintenance, and site-specific management for forest land in northwest Ontario. Northwest Sci. and Technol., Ont. Min. Nat. Resour., Thunder Bay. NWST Tech. Rept. TR-105. 111 pp.

Chen, J. M. 1996. Optically-based methods for measuring seasonal variation of leaf area index in boreal conifer stands. Agric. For. Meteorol. **80**: 135 - 163.

Cole, D. W., and M. Rapp. 1981. Elemental cycling in forest ecosystems. pp. 341 - 409. *In* Dynamic principles of forest ecosystems. Reichle, D. E. Ed. Cambridge Univ. Press, London. 1981. 683 pp.

Corns, I. G. W. 1978. Tree growth prediction and plant community distribution in relation to environmental factors in lodgepole pine, white spruce, black spruce and aspen forests of western Alberta foothills. Unpubl. Ph. D. dissertation. Univ. of Alberta, Edmonton, Alberta.

Environment Canada. 1998. Canadian Climate Normals 1961 to 1990. www.cmc.ec.gc.ca/climate/normals/E_AL_NDX.HTM. Accessed: 15 November, 2000. Environment Canada.

Fassnacht, K. S., and S. T. Gower. 1997. Interrelationships among the edaphic and stand characteristics, leaf area index, and above ground net primary production of upland forest ecosystems in north central Wisconsin. Can. J. For. Res. **27**: 1058 - 1067.

Fyles, J. W., and W. B. McGill. 1987. Nitrogen mineralization in forest soil profiles from central Alberta. Can. J. For. Res. **17**: 242 - 249.

Gower, S., and J. M. Norman. 1991. Rapid estimation of leaf area index in conifer and broad-leaf plantations. Ecology **72**: 1896 - 1900.

Hall, R. J. 1998a. LAI measurement in mixedwood forest stands. Email, Thursday, June 11, 1998, 1:14 PM.

Hall, R. J. 1998b. Special lecture - leaf area index ver. 1.1. Nat. Resour. Can., Can. For. Serv., North. For. Cent. Lecture, August 1998.

Huang, W. Z., and J. J. Schoenau. 1996. Forms, amounts and distribution of carbon, nitrogen, phosphorus and sulfur in a boreal aspen forest soil. Can. J. Soil Sci. **76**: 373-385.

Huang, W. Z., and J. J. Schoenau. 1997. Seasonal and spatial variations in soil nitrogen and phosphorus supply rates in a boreal aspen forest. Can. J. Soil Sci. **77**: 597 - 612.

Johnson, R. A., and G. K. Bhattacharyya. 1992. Statistics: principles and methods. 2nd. John Wiley & Sons, New York. 686 pp.

Kimmins, J. P. 1987. Forest ecology. Collier Macmillian Pub., London. 531 pp.

Li-Cor Inc. n.d. The LAI-2000 Plant Canopy Analyzer. Li-Cor Inc., Lincoln.

Lowe, L. E. 1972. Aspects of chemical variability in forest humus layers under mature western hemlock - western red cedar stands. Can. J. For. Res. **2**: 487 - 489.

MacLeod, W. K., and A. W. Blyth. 1955. Yield of even-aged fully stocked spruce-poplar stands in northern Alberta. Dept. of For. Res., For. Res. Branch, Ottawa. Tech. Note No. 18. 34 pp.

McClave, J. T., and F. H. Dietrich II. 1991. Statistics. Collier MacMillian Canada, Toronto. 928 pp.

Metz, L. J., C. G. Wells, and B. F. Swindel. 1966. Sampling soil and foliage in a pine plantation. Soil Sci. Soc. Am. Proc. **30**: 397-399.

Microsoft. 1998. Microsoft Excel 98 Macintosh Edition.

Munson, A. D., and V. R. Timmer. 1991. Site-specific growth and nutrition of planted *Picea mariana* in the Ontario Clay Belt. V. Humus nitrogen availability. Can. J. For. Res. **21**: 1194 - 1199.

Nadelhoffer, K. J., J. D. Aber, and J. M. Melillo. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. Plant and Soil **80**: 321 - 335.

Offord, J. L. 1999. Nitrogen mineralization patterns in boreal forest soils. Unpubl. M. Sc. thesis. Univ. of Alberta, Edmonton, Alberta. 183 pp.

Quesnel, H. J., and L. M. Lavkulich. 1980. Nutrient variability of forest floors near Port Hardy, British Columbia, Canada. Can. J. Soil Sci. **60**: 565 - 573.

Ryan, T. P. 1997. Modern regression methods. John Wiley & Sons, Inc., Toronto. 515 pp.

Soil Science Society of America. 1998. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 15 November, 2000. Soil Science Society of America.

Soil Survey Staff. 1998. Keys to soil taxonomy. 8th. U.S. Dept. of Agric., Nat. Resour. Conserv. Serv., Washington, D.C. 326 pp.

SPSS. 1995. SPSS 6.1.1 for Power Macintosh.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics. 2nd. McGraw-Hill, New York. 633 pp.

Twardy, A. G., and I. G. W. Corns. 1980. Soil survey and interpretations of the Wapiti map area, Alberta. Alberta Res. Coun., Edmonton, Alberta, 134 pp.

Chapter 6

Synthesis

6.1 Introduction

An approach to forest management that can provide for forest values (*e.g.*, forest products, recreation, aesthetics, wildlife, and natural ecosystems) through high-yield plantations, multiple use forest areas, and ecological reserves encompassing a wide range of forest types and site-qualities (Seymour and Hunter, 1994). This concept of forest management suggests that "truly intensive, very high yield silviculture could enhance society's opportunity to establish ecological reserves" (Seymour and Hunter, 1994). High yield sites can relieve the pressures for forest products from the rest of the forest because they can provide greater yield per unit area and shorter rotations.

6.1.1 Identification of high-yield sites

The challenge to develop a system of forest management for boreal mixedwood forests that is similar to the system proposed by Seymour and Hunter (1994), is categorizing forest-site productivity. The boreal mixedwood forest occupies about one-fourth of Alberta's forest types (Canadian Forest Service, 2000). Identifying high-yield areas is necessary to increase production with intensive silviculture as well as ensuring the complete range of forest-site productivity types are represented in multiple use and ecological reserve forest areas.

To identify high-yield areas one must be able to evaluate forest-site productivity, also referred to as forest-site quality, or the ability of a site to produce tree growth (MacLeod and Blyth, 1955; Carmean, 1996). There are few long-term forest management records available in the Canadian boreal forest from which forest-site quality can be determined. Therefore, alternative methods of evaluating forest-site quality are necessary.

Other than using long-term management records, there are two alternatives to evaluating forest-site quality. These two alternatives are indirect measurement of maximum tree productivity, *e.g.*, site index, or indirectly from calibrated soil-site models, also referred to as soil-site evaluation equations.

6.1.2 Advantages of soil-site evaluation

6.1.2.1 Applications in forest management

Use of soil and site condition relationships with plant community productivity can provide a means of evaluating forest-site quality. In addition, periodic assessments can be used to monitor soil quality over the duration of a management plan to help indicate sustainable forest practices. Such monitoring is necessary for soil resource management (Halvorson *et al.*, 1996) and for certification according to the

policies of some agencies responsible for certification of sustainable forest management, e.g., the Canadian Standard Association (1996).

6.1.2.2 Use in even- and uneven-aged forests

Soil-site evaluation equations are more appropriate for application in uneven-aged or mixedwood stands than the more common direct methods of evaluating forest-site productivity. Soil-site equations are mathematical models that can be used to estimate forest-site quality from given soil-plant relationships. Regression of a variety of forest productivity estimates on influential soil properties is used to calibrate the models. Appropriate models can be used to evaluate even- and uneven-aged forest-site quality. A common direct method of evaluating forest-site quality is site index (Carmean, 1996), and it is best used in even-aged stands. Site index regressed on soil properties generates soil-site equations appropriate for even-aged forests. Many studies have been done this way (Heger, 1971; Husch *et al.*, 1982; Payandeh, 1986; Jokela *et al.*, 1988; Newnham, 1988; Schmidt and Carmean, 1988; Carmean and Lenthall, 1989; Klinka *et al.*, 1989; Wang, 1995; Wang and Klinka, 1996; Carmean and Li, 1998; Chen Han *et al.*, 1998).

Unfortunately, site index is not appropriate for estimation of mixedwood site productivity. Site index requires the selection of dominant trees that have not experienced a different intensity and duration of growth suppression than its neighbours. In an uneven-aged forest the intensity and duration of relatively shade tolerant species, such as white spruce, is highly variable. Selection of a dominant tree in a mixedwood stand may not indicate the maximum attainable productivity, and therefore cause an underestimation of forest-site quality.

Soil-site evaluation equations can estimate productivity of mixedwood stands. Fundamental estimates of forest-site quality such as net primary productivity are more appropriate for mixedwood stands *cf.* site index. Net primary productivity is a measure of the accumulation of plant community biomass after losses due to respiration and consumption. Therefore net primary productivity can be applied in even- and uneven-aged stands. This could be considered an ecological approach (Gholz, 1982; Waring and Schlesinger, 1985; Kimmins, 1996; Fassnacht and Gower, 1997).

A proxy of net primary productivity is leaf area at maximum foliar capacity since it is the site for photosynthesis (Gholz, 1982; Webb *et al.*, 1983; Waring and Schlesinger, 1985). In a 70-year old fire-origin aspen forest growing in silty-clay texture Orthic Gray Luvisolic soil in central Saskatchewan, the seasonal period for maximum foliar capacity was mid-July (Black *et al.*, 1996). Use of soil property variables to estimate net primary productivity by leaf area index may provide a longer time period for evaluating site-quality than directly measuring leaf area by instrument, since the latter estimate should be obtained during the period of maximum foliar capacity. Also, use of leaf area as a surrogate of net primary productivity and as a dependent variable in the soil-site equations provides more versatility than the use of site index; models of the former can be calibrated for even- and uneven-aged forests of different species.

6.2 Mixedwood soil-site evaluation in west-central Alberta

In this study our objectives were to develop an understanding of the distribution of selected soil properties and ecological response variables across a mixedwood landscape by analysis of about 0.1 to 0.5 km sections represented by toposequences (Figure 6-1). The desired result was the development of models that represent the relationships between the distribution of selected ecological response variables and influential soil properties.

6.2.1 Landscape distribution of ecological response variables

A few ecological response variables were examined, but not all were able to indicate differences across the landscape. Selected ecological response variables were leaf area index (projected leaf area in m^2 per ground area in m^2), basal area (m^2 ha^{-1}) and mean annual basal area increment (m^2 ha^{-1} a^{-1}). Leaf area index was the only ecological response variable sensitive enough to detect a difference ($p \leq 0.05$) between the top of the slope (crest, upper and middle) and the bottom (toe). Leaf area index values ranged from 2.8 ± 0.2 (crest) to 3.5 ± 0.2 m^2 m^{-2} (toe).

6.2.2 Landscape distribution of soil morphological and texture-associated properties

The landscape distribution of soil morphological (horizon thickness, bulk density, particle size, water and root distribution) and texture-associated properties (available water and available water capacity, cation exchange capacity, and soil pH in water) were examined on three toposequence sites. Physiographic trends in the soil properties suggested the topographic position had a dominant influence on forest-site quality, albeit in a few cases differences were not detectable ($p > 0.05$).

Differences were detected ($p \leq 0.05$) for the forest floor and A-horizon thickness. Forest floor thickness increased from crest (5 ± 2 cm) to toe (9 ± 3 cm), and A-horizon thickness from toe (17 ± 8 cm) to crest (29 ± 8 cm). Differences ($p \leq 0.05$) were detected in the A-horizon sand, silt and clay, and B-horizon silt contents. Particle size distribution suggests translocation of clay from the A- to the B-horizon was the dominant soil process. The clay translocation process appears to be most strongly expressed at the crest. This has influenced available water (mm) and available water capacity (mm). Available water capacity for the profile was greatest at the top of the slope, but available water was greatest at the bottom of the slope. The particle size distribution also caused a detectable difference in A-horizon estimated cation exchange capacity; increasing from crest (6.6 ± 0.6 cmol(+) kg^{-1}) to toe (9.4 ± 0.7 cmol(+) kg^{-1}). The observed distribution of roots indicated they concentrated in the forest floor and A-horizon (Figure 3-5). There appeared to be no change in the abundance of roots by soil horizon along the toposequence.

6.2.3 Forest floor development across selected landscapes

Nitrogen is the fourth most common element in plants and is commonly the nutrient element in shortest supply (Paul and Clark, 1996). Nitrogen deficiency in the boreal forest conifers is widespread (Huang and Schoenau, 1997). The study by Mugasha *et al.* (1991) is an example of research in the boreal forest suggesting N is limiting, particularly in bottom-slope positions (*e.g.*, Gleysolic soils) of central Alberta. Our examination of selected soil organic matter properties along a toposequence showed a detectable difference ($p \leq 0.05$) between the profile organic-C pool to *ca* 1.2 m depth at the crest (13.3 kg m^{-2}) and the toe position that was 63% greater at the same depth. The C/N ratio was greater ($p \leq 0.05$) at the toe in the forest floor (33 ± 2) and the A-horizon (16 ± 1). No differences were detectable ($p \leq 0.05$) for the net N mineralized, specific net N mineralized, or NO_3-N/NH_4-N ratio. The inherent spatial variation of net N mineralization is probably the reason that no trend is detectable ($p \leq 0.05$). Generally there was net mineralization at the crest and net immobilization at the toe slope position.

6.2.4 Soil-site productivity modeling

After reviewing the distribution of soil properties across the landscapes, those that best describe the variation in both leaf-area ecological response variables were: forest floor total N (g $100g^{-1}$) and bulk density (g cm^{-3}), and B-horizon silt content (g $100g^{-1}$) and permanent wilting point (cm). It appears that species composition of a site has a strong influence on the soil properties limiting net community productivity. Total N of the forest floor appeared to be correlated with leaf area variables of the coniferous component of the stand. Forest floor bulk density enhanced the description of the forest floor, which affected the supply of inorganic N to the coniferous component of the mixedwood stand. The B-horizon silt and permanent wilting point appear to describe landscape soil water relationships that are beneficial to mixedwood leaf area ecological response variables. The results were two models: one predicting LAI (eq. 5-1) as estimated by a Li-Cor LAI-2000 ($R^2 = 0.62$, MSE = 0.1253, df = 31) (Li-Cor Inc., n.d.), and the other LAI adjusted (by basal area) for species composition (eq 5-2; $R^2 = 0.70$, MSE = 0.2426, df = 31).

These two soil-site models can be applied in forestry to provide an assessment of potential forest-site quality with respect to the forest mixedwood community productivity. It may be a preferred method compared to measuring LAI directly. Direct measure of LAI for estimation of net primary productivity is best done during the period of maximum foliar capacity of a site. A soil-site equation will estimate LAI as a proxy of net primary productivity with respect to current soil properties regardless of the season and tree development (age). In addition periodic assessments of the models can be used for monitoring the stability of forest-soil quality for local mixedwoods.

The predictor variables for models developed in this study indicate the soil properties limiting local net primary productivity. Similar predictor variables have been suggested in another local soil-site study (Corns, 1978) as well as general boreal forest soil-site literature (Kimmins, 1996). In this study we

confirmed the importance of soil N and water, and we were able to hypothesize the biological association with leaf area of mixedwood community development in the local landscape.

In future work, considerations of the temporal variability of soil N and water will be important. In addition, defining the relationship between net primary productivity proxies and growth and yield estimates, *e.g.*, basal area and tree volume, of mixedwood forest stands will be valuable for direct application of soil-site equations to forestry operations. Already the LAI values can be correlated with the growth and yield variables: basal area ($r = -0.12$, $p = 0.456$), mean annual basal area increment (BAI; $r = 0.53$, $p = 0.001$), and tree volume ($r = -0.39$, $p = .014$).

6.3 Considerations for the future

In the future, more consideration should be given to spatial variability of soil properties and surrogate variables for plant community productivity in Alberta white spruce-aspen mixedwood communities. Also, the temporal variation inherent to estimates of inorganic soil N and water variables, as well as the possible inclusion of these variables incorporating their ephemeral properties in regression analysis with surrogates of net primary productivity.

Further considerations should also be given to the relationships between surrogates of net primary productivity (*e.g.*, leaf area variables) and growth and yield (*e.g.*, basal area and tree volume annual increments) values for species. This would improve the ability of forest managers to apply soil-site evaluation models in management planning, and perhaps as a tool to predict the effects of global change on forestry; with respect to rates of production.

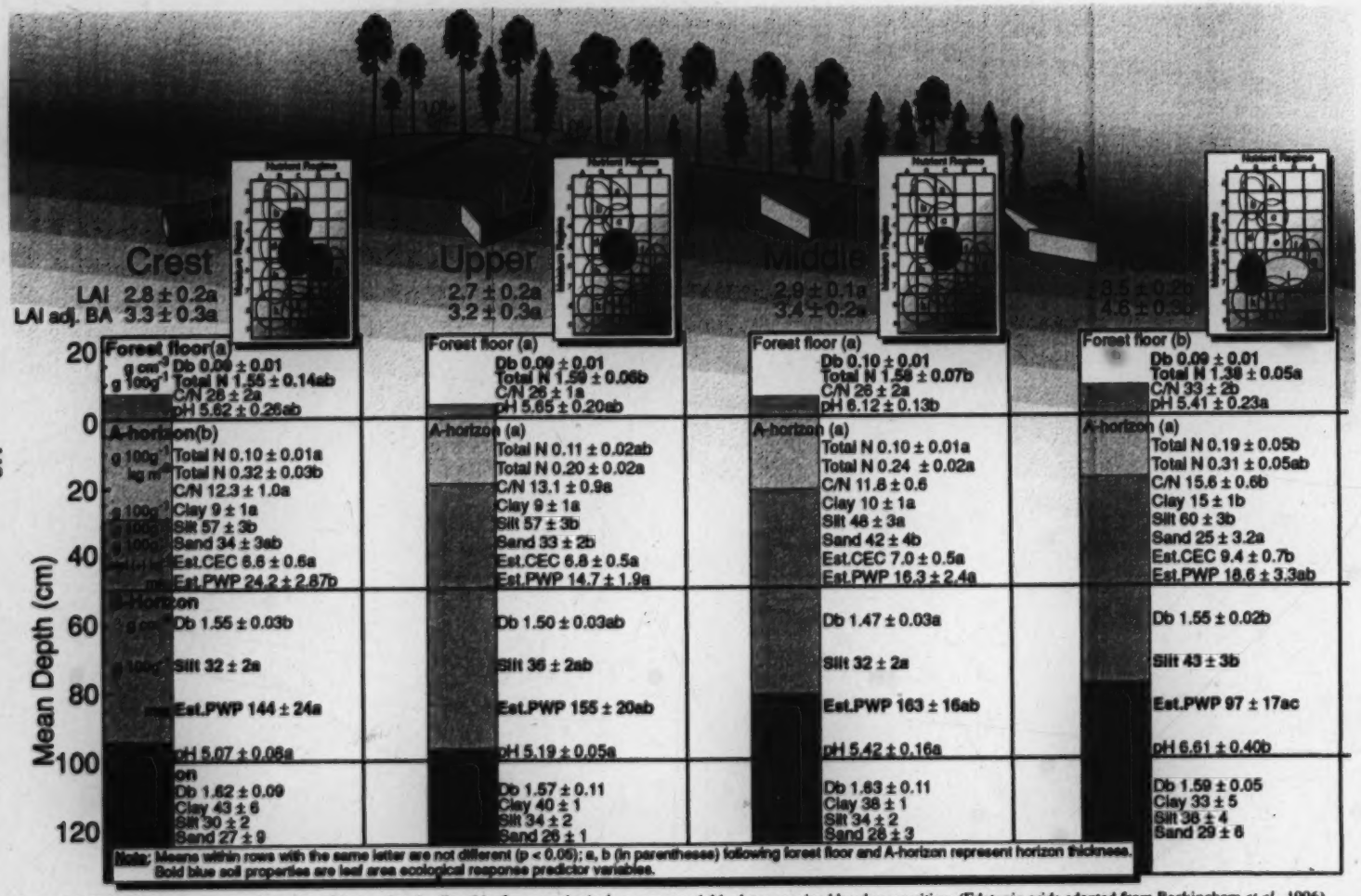

Figure 6-1. Schmatic toposequence depiction with associated soil and leaf area ecological response variable data organized by slope position. (Edatopic grids adapted from Beckingham *et al.*, 1996)

6.4 Literature cited

Black, T. A., G. DenHartog, H. H. Neumann, P. D. Blanken, P. C. Yang, C. Russell, Z. Nesic, X. Lee, S. G. Chen, R. Staebler, and M. D. Novak. 1996. Annual cycles of water vapour and carbon dioxide fluxes in and above a boreal aspen forest. Glob. Chang. Biol. **2**: 219 - 229.

Canadian Forest Service. 2000. The state of Canada's Forests 1999-2000 Forests in the new millennium. Nat. Resour. Can., Can. For. Serv., Ottawa. Fo 1-6/2000 E. 120 pp.

Canadian Standard Association. 1996. A sustainable forest management system: guidance document. CAN/CSA-Z808, environmental technology; a national standard of Canada. Canadian Standards Association, CAN/CSA-Z808-96. 33 pp.

Carmean, W. H. 1996. Forest site-quality estimation using forest ecosystem classification in Northwestern Ontario. Environ. Monit. Assess. **39**: 493 - 503.

Carmean, W. H., and D. J. Lenthall. 1989. Height-growth and site-index curves for jack pine in north central Ontario (Canada). Can. J. For. Res. **19**: 215 - 224.

Carmean, W. H., and J. Li. 1998. Soil-site relations for trembling aspen in northwest Ontario. Northern J. Appl. For. **15**: 146 - 153.

Chen Han, Y. H., K. Klinka, and R. D. Kabzems. 1998. Site index, site quality, and foliar nutrients of trembling aspen: Relationships and predictions. Can. J. For. Res. **28**: 1743 - 1755.

Corns, I. G. W. 1978. Tree growth prediction and plant community distribution in relation to environmental factors in lodgepole pine, white spruce, black spruce and aspen forests of western Alberta foothills. Unpubl. Ph. D. dissertation. Univ. of Alberta, Edmonton, Alberta.

Fassnacht, K. S., and S. T. Gower. 1997. Interrelationships among the edaphic and stand characteristics, leaf area index, and above ground net primary production of upland forest ecosystems in north central Wisconsin. Can. J. For. Res. **27**: 1058 - 1067.

Gholz, H. L. 1982. Environmental limits on above ground net primary production, leaf area, and biomass in vegetation zones of the Pacific Northwest. Ecology **63**: 469 - 481.

Halvorson, J. J., J. L. Smith, and R. I. Papendick. 1996. Integration of multiple soil parameters to evaluate soil quality: A field example. Biol. Fertil. Soils **21**: 207 -214.

Heger, L. 1971. Site-index/soil relationships for white spruce in Alberta mixedwoods. Forest Management Institute, Info. Rept. No. FMR-X-32. 15 pp.

Huang, W. Z., and J. J. Schoenau. 1997. Seasonal and spatial variations in soil nitrogen and phosphorus supply rates in a boreal aspen forest. Can. J. Soil Sci. **77**: 597 - 612.

Husch, B., C. I. Miller, and T. W. Beers. 1982. Forest mensuration. 3rd. John Wiley & Sons, New York. 402 pp.

Jokela, E. J., E. H. White, and J. V. Berglund. 1988. Predicting Norway spruce growth from soil and topographic properties in New York. Soil Sci. Soc. Am. J. **52**: 809 - 815.

Kimmins, J. P. 1996. Importance of soil and role of ecosystem disturbance for sustained productivity of cool temperate and boreal forests. Soil Sci. Soc. Am. J. **60**: 1643 - 1654.

Klinka, K., R. E. Carter, M. C. Feller, and Q. Wang. 1989. Relations between site index, salal, plant communities, and sites in coastal Douglas-fir ecosystems (British Columbia, Canada). Northwest Sci. **63**: 19 - 28.

Li-Cor Inc. n.d. The LAI-2000 Plant Canopy Analyzer. Li-Cor Inc., Lincoln.

MacLeod, W. K., and A. W. Blyth. 1955. Yield of even-aged fully stocked spruce-poplar stands in northern Alberta. Dept. of For. Res., For. Res. Branch, Ottawa. Tech. Note No. 18. 34 pp.

Mugasha, A. G., D. J. Pluth, K. O. Higginbotham, and S. K. Takyi. 1991. Foliar responses of black spruce to thinning and fertilization on a drained shallow peat. Can. J. For. Res. **21**: 152 - 163.

Newnham, R. M. 1988. A modification of the Ek-Payendeh nonlinear regression model for site index curves. Can. J. For. Res. **18**: 115 - 120.

Paul, E. A., and F. E. Clark. 1996. Soil microbiology and biochemistry. 2nd. Academic Press, Toronto. 340 pp.

Payandeh, B. 1986. Predictability of site index from soil factors and lesser vegetation in northern Ontario forest types. Great Lakes For. Cen., Can. For. Serv., Sault Ste. Marie. Fo46-14/373E. 12 pp.

Schmidt, M. G., and W. H. Carmean. 1988. Jack pine site quality in relation to soil and topography in north central Ontario (Canada). Can. J. For. Res. **18**: 297 - 305.

Seymour, R. S., and M. L. Hunter. 1994. New forestry in eastern spruce-fir forests: principles and applications to Maine. Maine Agric. and For. Expt. Stn., Misc. Rept. 716. 36 pp.

Wang, G., and K. Klinka. 1996. Use of synoptic variables in predicting white spruce site index. For. Ecol. Manage. **80**: 95 - 105.

Wang, G. G. 1995. White spruce site index in relation to soil, understory vegetation, and foliar nutrients. Can. J. For. Res. **25**: 29 - 38.

Waring, R. H., and W. H. Schlesinger. 1985. Forest ecosystem concepts and management. Academic Press, London. 340 pp.

Webb, W. L., W. K. Lauenroth, S. R. Szarek, and R. S. Kinerson. 1983. Primary production and abiotic controls in forests, grasslands, and desert ecosystems in the United States. Ecology **64**: 134 - 151.

APPENDICES

APPENDIX I

Soil Profile Descriptions.

References

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. Minister of Supply and Service Canada,. 164 pp.

Beckingham, J. D., I. G. W. Corns, and J. H. Archibald. 1996. Field guide to ecosites of west-central Alberta. Edmonton, Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent. Special Report 9.

Twardy, A. G., and I. G. W. Corns. 1980. Soil survey and interpretations of the Wapiti map area, Alberta. Soil Dept., Alberta Res. Coun., Alberta Inst. of Pedology. 134 pp.

Site Description		
Soil Classification:	Brunisolic Gray Luvisol (BR. GL)	
Toposequence:	1	Economy Tower transect
Transect Position:	35m	
Plot:	C	
Slope Position:	Crest	
Slope Gradient:	3%	Slope Class 3 - very gentle slope
Slope Aspect:	160	South Southwest
Drainage Class:	3	Well Drained
Plant Community:	LF - ¢2.3	Aw/Green alder (p. 7-44)
Humus Form:	Raw Moder	
Microsite:	<30%, few, large, even microrelief	
Parent Material:	Lacustrine over Edson continental till	

Horizon	Depth (cm)	Description
L	8.5 to 8	
F/H	8 to 0	Abundant, very fine to medium and plentiful, coarse, horizontal roots.
Ae1	0 to 11	Dark greyish yellow (2.5 Y 5/2) moist; silt loam; very weak, coarse, platy, strong, medium, platy; friable; abundant, very fine and coarse and plentiful, fine to medium, horizontal, inped and exped roots; abrupt, wavy boundary; 4-11 cm thick.
Ae2	11 to 18	Dull yellow orange (10 YR 6/4) dry; silt clay loam; very weak, coarse, subangular blocky, strong, medium, platy; soft; plentiful, very fine and medium and few, fine and coarse, horizontal, inped and exped roots; clear, wavy boundary; 7-17 cm thick.
Ae3	18 to 28	Greyish yellow (2.5 Y 7/2) dry; silt clay loam; very weak, medium, subangular blocky, strong, medium, platy; slightly hard; plentiful, very fine to fine and few, medium, horizontal, inped and exped roots; clear, smooth boundary; 6-10 cm thick.
AB	28 to 35	Dull yellow (2.5 Y 6/4) dry; silty clay; weak, coarse, subangular blocky, moderate, fine, subangular blocky; slightly hard to hard; plentiful, very fine to medium, horizontal, exped roots; abrupt, smooth boundary; 6-10 cm thick.
Btnj	35 to 62	Olive brown (2.5 Y 4/4) dry; clay loam; strong, medium, prismatic, weak, medium, subangular blocky; hard; few, very fine to fine, vertical, exped roots; clear, smooth boundary; 27-33 cm thick.
BC	62 to 75	Dark brown (10 YR 3/3) dry; clay loam; moderate, fine, prismatic, weak, medium, subangular blocky; hard; few, very fine to fine, vertical, exped roots; gradual, smooth boundary; 10-13 cm thick.
Cca	75 +	Dark brown (10 YR 3/3) dry; clay; massive, moderate, fine, subangular blocky; slightly hard; few, fine, vertical, exped roots; gradual, smooth boundary; moderately effervescent.

Site Description		
Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	1	Economy Tower transect
Transect Position:	80m	
Plot:	C	
Slope Position:	Upper Slope	
Slope Gradient:	16%	Slope Class 6 - strong slope
Slope Aspect:	176	South Southeast
Drainage Class:	3	Well Drained
Plant Community:	LF - e2.4	Aw/low-bush cranberry (p. 7-44)
Humus Form:	Raw Moder	
Microsite:	30-60%, plentiful, small, mild microrelief	
Parent Material:	Till	

Horizon	Depth (cm)	Description
L	5 to 4	
F/H	4 to 0	Abundant, very fine to fine and plentiful, medium to coarse, horizontal roots.
Ae	0 to 6	Greyish brown (7.5 YR 5/2) wet; very weak, fine, subangular blocky, weak, fine, granular; slightly sticky; plentiful, very fine to medium and few, coarse, horizontal, inped and exped roots; abrupt, wavy boundary; 3-5 cm thick.
Bt	6 to 54	Dull yellowish brown (10 YR 5/4) moist; moderate, fine, prismatic, very weak, medium, subangular blocky; very firm; plentiful, very fine to medium, horizontal, exped roots; clear, wavy boundary; 48-51 cm thick.
BC	54 to 96	Dark brown (10 YR 3/4) moist; very weak, fine, prismatic, strong, fine, subangular blocky; very firm; few, very fine and medium, horizontal, exped roots; gradual, smooth boundary; 43-48 cm thick.
Ck	96 +	Dark brown (10 YR 3/4) moist; massive, moderate, fine, subangular blocky; very firm; gradual, smooth boundary; very weakly effervescent.

Site Description

Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	1	Economy Tower transect
Transect Position:	100m	
Plot:	C	
Slope Position:	Middle Slope	
Slope Gradient:	23%	Slope Class 6 - strong slope
Slope Aspect:	202	South Southwest
Drainage Class:	4	Moderately Well Drained
Plant Community:	LF - e2.4	Aw/low-bush cranberry (p. 7-44)
Humus Form:	Raw Moder	
Microsite:	30-60%, plentiful, small, mild microrelief	
Parent Material:	Till	

Horizon	Depth (cm)	Description
L	6 to 5	
F/H	5 to 0	Abundant, very fine to fine and plentiful, medium to coarse, horizontal roots.
Ae1	0 to 8	Dull yellowish brown (10 YR 5/4) moist; sandy clay loam; very weak, medium, subangular blocky, weak to moderate, fine, granular; very friable; abundant, very fine to fine, plentiful, medium and few, coarse, horizontal, inped and exped roots; abrupt, wavy boundary; 7-8 cm thick.
Ae2	8 to 15	Brown (10 YR 4/6) moist; silt clay loam; very weak, fine, subangular blocky, weak, fine, platy; friable; plentiful, very fine and medium and abundant, fine, horizontal, inped and exped roots; clear, wavy boundary; 7-10 cm thick.
Bt	15 to 63	Dull yellowish brown (10 YR 4/3) moist; clay; moderate, medium, prismatic, moderate, fine, subangular blocky; firm; plentiful, very fine and few, fine, vertical, exped roots; gradual, smooth boundary; 40-48 cm thick.
BC	63 to 87	Dark brown (7.5 YR 3/4) moist; clay loam; moderate, medium, prismatic, moderate, fine, subangular blocky; firm; few, very fine to fine, vertical, inped and exped roots; gradual, smooth boundary; 23-28 cm thick.
Ck	87 +	Dark brown (7.5 YR 3/4) moist; clay loam; massive, moderate, fine, subangular blocky; firm; gradual, smooth boundary; very weakly effervescent.

Site Description

Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	1	Economy Tower transect
Transect Position:	120m	
Plot:	C	
Slope Position:	Middle Slope	
Slope Gradient:	19%	Slope Class 6 - strong slope
Slope Aspect:	212	South Southwest
Drainage Class:	4	Moderately Well Drained
Plant Community:	LF - f2.3	Aw-Pb/dogwood/fern (p. 7-58)
Humus Form:	Raw Moder	
Microsite:	>60%, plentiful, small, mild microrelief	
Parent Material:	Till	

Horizon	Depth (cm)	Description
L	11 to 10	
F/H	10 to 0	Abundant, very fine and plentiful, fine to coarse, horizontal roots.
Ae1	0 to 9	Greyish yellow brown (10 YR 6/2) moist; silt clay loam; very weak, coarse, platy, weak, medium, platy; friable; plentiful, very fine and few, fine to coarse, oblique, inped and exped roots; abrupt, wavy boundary; 4-9 cm thick.
Ae2	9 to 14	Olive brown (2.5 Y 4/6) moist; silt clay loam; very weak, coarse, platy, weak, fine, platy; friable; few, very fine to fine, horizontal, inped and exped roots; clear, wavy boundary; 3-7 cm thick.
Bt	14 to 41	Dull yellowish brown (10 YR 4/3) moist; clay; strong, coarse, prismatic, very weak, coarse, subangular blocky; firm; few, very fine to medium, vertical, exped roots; clear, wavy boundary; 23-30 cm thick.
BC	41 to 74	Dark brown (10 YR 3/3) moist; clay loam; very weak, fine, prismatic, moderate, medium, subangular blocky; very firm; few, very fine to medium, vertical, exped roots; gradual, smooth boundary; 30-36 cm thick.
C	74 +	Brownish black (10 YR 2/3) moist; clay loam; massive, moderate, fine, subangular blocky; very firm; few, very fine to fine, vertical, exped roots; gradual, smooth boundary.

Site Description		
Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	1	Economy Tower transect
Transect Position:	150m	
Plot:	C	
Slope Position:	Lower Slope	
Slope Gradient:	13%	Slope Class 5 - moderate slope
Slope Aspect:	210	South Southwest
Drainage Class:	5	Imperfectly Drained
Plant Community:	LF - f4.1	Aw/bracted honeysuckle/fern (p. 7-66)
Humus Form:	Raw Moder	
Microsite:	30-60%, few, small, mild microrelief	
Parent Material:	Till	

Horizon	Depth (cm)	Description
L	8 to 7	
F/H	7 to 0	Abundant, very fine to fine, plentiful, medium and few, coarse, horizontal roots.
Aeg	0 to 21	Greyish yellow brown (10 YR 6/2) moist; silt clay loam; many, medium, prominent, yellowish brown (2.5 Y 5/6) mottles; moderate, medium, platy, strong, fine, platy; friable; abundant, very fine to fine and plentiful, medium to coarse, horizontal, inped and exped roots; clear, smooth boundary; 15-22 cm thick.
AB	21 to 31	Yellowish brown (10 YR 5/6) moist; clay loam; moderate, medium, subangular blocky, weak, fine, subangular blocky; firm; few, very fine to fine, oblique, exped roots; clear, smooth boundary; 5-11 cm thick.
Bt	31 to 62	Brownish black (2.5 Y 3/2) moist; clay loam; weak, fine, prismatic, weak, medium, subangular blocky; firm; few, very fine to fine and coarse, oblique, exped roots; clear, smooth boundary; 30-32 cm thick.
BC	62 to 88	Olive brown (2.5 Y 4/3) moist; clay loam; very weak, fine, prismatic, moderate, fine, subangular blocky; firm; few, very fine to medium, vertical, exped roots; gradual, smooth boundary; 25-27 cm thick.
Ck	88 +	Brown (10 YR 4/4) moist; clay loam; very weak, medium, subangular blocky, weak, fine, subangular blocky; firm; few, fine, vertical, exped roots; gradual, smooth boundary; weakly effervescent.

Site Description		
Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	1	Economy Tower transect
Transect Position:	180m	
Plot:	C	
Slope Position:	Low Slope	
Slope Gradient:	8%	Slope Class 4 - gentle slope
Slope Aspect:	198	South Southwest
Drainage Class:	4	Moderately Well Drained
Plant Community:	LF - i3.2	Sw/feathermoss (p. 7-86)
Humus Form:	Raw Moder	
Microsite:	>60%, abundant, small, pronounced microrelief	
Parent Material:	Colluvium over lacustrine	

Horizon	Depth (cm)	Description
L	14 to 13	
F/H	13 to 0	Abundant, very fine to fine and plentiful, medium to coarse, horizontal roots.
Aeg	0 to 21	Yellowish grey (2.5 Y 5/1) moist; few, fine, prominent, dull yellowish orange (10 YR 6/3) mottles; loam; very weak, coarse, platy, moderate, medium, platy; friable; few, very fine to medium, horizontal, inped and exped roots; abrupt, smooth boundary; 18-2 cm thick.
Bt	21 to 61	Brownish black (2.5 Y 3/2) moist; clay; very weak, fine, prismatic, moderate, fine, subangular blocky; firm; few, very fine to coarse, vertical, exped roots; clear, smooth boundary; 39-42 cm thick.
IIBC	61 to 80	Dull yellowish brown (10 YR 4/3) moist; silt clay loam; massive, weak, fine, subangular blocky; very friable; few, very fine to medium, horizontal, exped roots; clear, smooth boundary; 17-20 cm thick; weakly effervescent.
IICk	80 +	Dark olive brown (2.5 Y 3/3) moist; silt clay loam; massive; few, very fine to fine roots; clear, smooth boundary; moderately effervescent.

Site Description		
Soil Classification:	Orthic Luvic Gleysol (O. LG)	
Toposequence:	1	Economy Tower transect
Transect Position:	200m	
Plot:	C	
Slope Position:	Toe	
Slope Gradient:	3%	Slope Class 3 - very gentle slope
Slope Aspect:	208	South Southwest
Drainage Class:	5	Imperfectly Drained
Plant Community:	LF - i3.2	Sw/feathermoss (p. 7-86)
Humus Form:	Fibrimor	
Microsite:	>60%, plentiful, large, pronounced microrelief	
Parent Material:	Colluvium over lacustrine	

Horizon	Depth (cm)	Description
L	9.5 to 8	
F/H	8 to 0	Abundant, very fine, plentiful, fine to medium and few, coarse, horizontal roots.
Aeg	0 to 30	Brownish grey (10 YR 5/1) moist; silt loam; many, medium, distinct, brown (10 YR 4/4) mottles; very weak, fine, subangular blocky, weak, medium, platy; friable; plentiful, very fine to medium, few, coarse, oblique, inped and exped roots; clear, smooth boundary; 23-30 cm thick.
Btg	30 to 69	Greyish brown (10 YR 4/2) moist; silt clay loam; many, fine, distinct, brown (10 YR 4/6) mottles; very weak, fine, prismatic, weak, medium, subangular blocky; friable; few, very fine to fine, horizontal, exped roots; clear, smooth boundary; 36-39 cm thick.
IIBCkg	69 to 96	Dull yellowish brown (10 YR 4/3) moist; clay loam; common, fine, distinct, brown (10 YR 4/6) mottles; weak, fine, subangular blocky; few, very fine to medium, horizontal, exped roots; gradual, smooth boundary; 21-28 cm thick; weakly effervescent.
IICcag	96 +	Greyish yellow brown (10 YR 5/2) moist; silt clay loam; common, fine, distinct, brown (10 YR 4/4) mottles; massive; gradual, smooth boundary; moderately effervescent.

Site Description		
Soil Classification:	Terric Mesisol (T. M)	
Toposequence:	1	Economy Tower transect
Transect Position:	280m	
Plot:	C	
Slope Position:	Depression	
Slope Gradient:	0%	Slope Class 1 - level
Slope Aspect:	N/A	
Drainage Class:	7	Poorly Drained
Plant Community:	LF - 11.1	Sb-Lt/dwarf birch/sedge/peat moss (p. 7-100)
Humus Form:	Mesic peatymor	
Microsite:	>60%, plentiful, large, strong microrelief	
Parent Material:	Organic Soil	

Horizon	Depth (cm)	Description
L	60 to 61	
F/H	61 to 55	Abundant, very fine to fine, plentiful, medium and few, coarse, horizontal roots.
Om	55 to 0	Black (N 1.5/0); abundant, very fine to fine, plentiful, medium and few, horizontal roots; wavy, clear boundary; 51-57 cm thick.
Cg	0 +	Brownish grey (10 YR 4/1) moist; silt clay loam; many, coarse, prominent, olive brown (2.5 Y 4/4) mottles; massive; firm; wavy, clear boundary.

Site Description		
Soil Classification:	Brunisolic Gray Luvisol (BR. GL)	
Toposequence:	2	CanFor Haul Road No. 2 transect
Transect Position:	12.5m	
Plot:	C	
Slope Position:	Crest	
Slope Gradient:	5%	Slope Class 3 - very gentle slope
Slope Aspect:	140	South East
Drainage Class:	3	Well Drained
Plant Community:	LF - c3.2	Aw-Sw-Pl/green alder/hairy wild rye (p. 7-32)
Humus Form:	Fibrimor	
Microsite:	<30%, very few, large, pronounced microrelief	
Parent Material:	Eolian sediment over lacustro-till (ice-rafted till)	

Horizon	Depth (cm)	Description
L	3 to 2	
F/H	2 to 0	Abundant, very fine and plentiful, fine to coarse, horizontal roots.
Ae1	0 to 9	Brownish grey (10 YR 6/1) moist; silt; weak, coarse, platy, moderate to strong, fine, platy; very friable; abundant, very fine, and plentiful, fine to coarse, horizontal, inped and exped roots; abrupt, smooth boundary; 5 to 9 cm thick.
Bm	9 to 16	Yellowish brown (10 YR 5/6) moist; silt clay loam; weak, coarse, subangular blocky, moderate, fine, platy; friable; plentiful, very fine to medium and few, coarse, horizontal, inped and exped roots; abrupt, wavy boundary; 4 to 8 cm thick.
Ae2	16 to 29	Light yellow (2.5 Y 7/3) moist; silt clay loam; weak, coarse, platy, moderate, fine, platy; friable; few, very fine to coarse, oblique, inped and exped roots; clear, smooth boundary; 10 to 13 cm thick.
IIBt1	29 to 63	Dull yellowish brown (10 YR 5/4) moist; clay; weak to moderate, fine, prismatic, strong, coarse, subangular blocky; very firm; few, very fine to coarse, oblique, exped roots; abrupt, smooth boundary; 30 to 35 cm thick.
IIBt2	63 +	Olive brown (2.5 Y 4/3) moist; silt clay loam; very weak, coarse, prismatic, very weak, very coarse, subangular blocky; very firm; few, very fine to medium, vertical, exped roots; clear, smooth boundary.

Site Description		
Soil Classification:	Brunisolic Gray Luvisol (BR. GL)	
Toposequence:	2	CanFor Haul Road No. 2 transect
Transect Position:	50m	
Plot:	C	
Slope Position:	Upper Slope	
Slope Gradient:	19%	Slope Class 6 - strong slope
Slope Aspect:	140	South East
Drainage Class:	3	Well Drained
Plant Community:	LF - e4.3	Sw/prickly rose (p. 7-50)
Humus Form:	Fibrimor	
Microsite:	>60%, abundant, small, mild microrelief	
Parent Material:	Lacustro-till or glacialfluvial	

Horizon	Depth (cm)	Description
L	7 to 6	
F/H	6 to 0	Abundant, very fine to medium and plentiful, coarse, horizontal roots.
Ae1	0 to 5	Light grey (10 YR 7/1) moist; sandy loam; very weak, coarse, platy, strong, medium, platy; very friable; plentiful, very fine to medium and few, coarse, oblique, inped and exped roots; abrupt, wavy boundary; 5 to 7 cm thick.
Bm	5 to 14	Yellowish brown (10 YR 5/8) moist; sandy loam; very weak, fine, subangular blocky, weak, fine, platy; very friable; plentiful, very fine to medium and few, coarse, oblique, inped and exped roots; abrupt, wavy boundary; 4-9 cm thick.
Ae2	14 to 22	Greyish yellow (2.5 Y 7/4) moist; sandy loam; weak, fine, subangular blocky, weak, medium, platy; friable; few, very fine to coarse, oblique, inped and exped roots; gradual, smooth boundary; 7-8 cm thick.
Bt1	22 to 67	Dull yellow (2.5 Y 6/3) dry; loam; very weak, medium, prismatic, strong, fine, subangular blocky; hard; few, very fine to medium, vertical, exped roots; gradual, smooth boundary; 42-47 cm thick.
Bt2	67 +	Dull yellowish brown (10 YR 5/3) moist; loam; very weak, fine, prismatic, moderate, fine, subangular blocky; firm; few, very fine to fine, vertical, exped roots; diffuse, smooth boundary.

Site Description		
Soil Classification:	Brunisolic Gray Luvisol (BR. GL)	
Toposequence:	2	CanFor Haul Road No. 2 transect
Transect Position:	65m	
Plot:	C	
Slope Position:	Lower Slope	
Slope Gradient:	26%	Slope Class 6 - strong slope
Slope Aspect:	138	South East
Drainage Class:	3	Well Drained
Plant Community:	LF - e4.1	Sw/green alder (p. 7-50)
Humus Form:	Fibrimor	
Microsite:	<30%, few, small, even microrelief	
Parent Material:	Colluvial over lacustrine	

Horizon	Depth (cm)	Description
L	7 to 6	
F/H	6 to 0	Abundant, very fine and plentiful, fine to coarse, horizontal roots.
Ae	0 to 11	Brownish grey (10 YR 6/1) moist; sandy loam; very weak, fine, subangular blocky, weak, fine, platy; friable; plentiful, very fine to coarse, horizontal, inped and exped roots; abrupt, smooth boundary; 6-11 cm thick.
Bm	11 to 24	Dull brown (7.5 YR 5/4) moist; sandy loam; very weak, medium, platy, single-grain; very friable; plentiful, very fine to medium and few, coarse, oblique, inped and exped roots; clear, smooth boundary; 13-20 cm thick.
Bt	24 to 38	Dull yellow (2.5 Y 6/3) moist; silt clay loam; very weak, fine, prismatic, strong, fine, subangular blocky; firm; plentiful, very fine to fine, and few, medium, horizontal, inped and exped roots; gradual, wavy boundary; 10-16 cm thick.
IIBt	38 to 91	Dull yellowish brown (10 YR 5/4) dry; silt clay loam; very weak, fine, prismatic, moderate, medium, subangular blocky; hard; few, very fine to medium, horizontal, exped roots; diffuse, smooth boundary; 50-55 cm thick.
IIC	91 +	Dark olive brown (2.5 Y 3/3) moist; loam; massive, moderate, coarse, platy; firm; few, very fine to medium, horizontal, exped roots; diffuse, smooth boundary.

Site Description		
Soil Classification:	Gleyed Eluviated Eutric Brunisol (GLE. EB)	
Toposequence:	2	CanFor Haul Road No. 2 transect
Transect Position:	85m	
Plot:	C	
Slope Position:	Toe	
Slope Gradient:	4%	Slope Class 3 - very gentle slope
Slope Aspect:	142	South East
Drainage Class:	5	Imperfectly Drained
Plant Community:	LF - h1.1	Sb-Pl/Labrador tea/feather moss (p. 7-78)
Humus Form:	Raw Moder	
Microsite:	>60%, abundant, small, pronounced microrelief	
Parent Material:	Eolian sediment over lacustro-till	

Horizon	Depth (cm)	Description
L	10 to 9	
F	9 to 4	Plentiful, very fine and few, fine, random roots.
Hi	4 to 0	Plentiful, very fine and medium and few, fine, random roots.
Ae	0 to 13	Dark greyish yellow (2.5 Y 4/2) moist; silt clay loam; weak, medium, blocky, moderate, medium, platy; friable; few, very fine to fine and coarse and plentiful, medium, random, inped and exped roots; abrupt, wavy boundary; 5-13 cm thick.
Btj	13 to 41	Dark olive brown (2.5 Y 3/3) moist; silt clay loam; weak, medium, prismatic, weak, medium, blocky; firm; few, very fine to coarse, horizontal, inped and exped roots; gradual, wavy boundary; 21 - 28 cm thick.
Cg	41 to 86	Yellowish grey (2.5 Y 4/1); silt clay loam; many, medium, distinct, olive brown (2.5 Y 4/4) mottles; massive; few, very fine to fine, horizontal roots; clear, smooth boundary; 37-45 cm thick.
IICgk	86 +	Brownish grey (10 YR 5/1); clay loam; many, coarse, distinct, dull yellowish brown (10 YR 5/4) mottles; massive; clear, smooth boundary; moderately effervescent.

Site Description		
Soil Classification:	Terric Mesisol (T. M)	
Toposequence:	2	CanFor Haul Road No. 2 transect
Transect Position:	110m	
Plot:	C	
Slope Position:	Depression	
Slope Gradient:	0%	Slope Class 1 - level
Slope Aspect:	N/A	
Drainage Class:	7	Poorly Drained
Plant Community:	LF - c3.2	Sw/feather moss (p. 7-86)
Humus Form:	Fibric peatymor	
Microsite:	>60%, abundant, small, pronounced microrelief	
Parent Material:	Organic Soil	

Horizon	Depth (cm)	Description
L	74 to 71	
Of	71 to 32	Yellow (2.5 Y 8/6); plentiful, very fine to coarse, horizontal roots; gradual, smooth boundary; 29-49 cm thick.
Om	32 to 0	Black (N 1.5/0); few, very fine to coarse, horizontal roots; gradual, smooth boundary; 32-40 cm thick.
Cg	0 +	Brownish grey (10 YR 5/1); moist; clay; many, coarse, prominent, dull reddish brown (5 YR 4/3) mottles; massive; friable; clear, wavy boundary.

Site Description		
Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	3	gas well transect
Transect Position:	10m	
Plot:	C	
Slope Position:	Upper Slope	
Slope Gradient:	4%	Slope Class 3 - very gentle slope
Slope Aspect:	354	North
Drainage Class:	4	Moderately Well Drained
Plant Community:	LF - f3.1	Aw-Sw-Pl/bracted honeysuckle/fern (p. 7-62)
Humus Form:	Fibrimor	
Microsite:	>60%, abundant, small, mild microrelief	
Parent Material:	Lacustro-till	

Horizon	Depth (cm)	Description
L	5 to 4	
F/H	4 to 0	Plentiful, very fine to coarse, random roots.
Ae	0 to 6	Light grey (10 YR 7/1) dry; silt clay loam; moderate, fine, blocky, weak, medium, platy; slightly hard; plentiful, very fine to medium, horizontal, inped and exped roots; abrupt, smooth boundary; 2-8 cm thick.
AB	6 to 19	Dull yellowish orange (10 YR 6/3) dry; clay loam; very weak, medium, prismatic, moderate, medium, subangular blocky; hard; plentiful, very fine to fine and few, medium, oblique, exped roots; clear, wavy boundary; 5-13 cm thick.
Bt1	19 to 41	Yellowish brown (2.5 Y 5/3) moist; clay; weak, medium, prismatic, moderate, fine, subangular blocky; firm; few, very fine to fine, vertical, exped roots; gradual, wavy boundary; 15-22 cm thick.
Bt2	41 to 69	Dark olive brown (2.5 Y 3/3) moist; clay; weak, coarse, prismatic, weak, medium, subangular block; firm; few very fine to fine, oblique, exped roots; clear, smooth boundary; 25-28 cm thick.
BC	69 to 86	Dark greyish yellow (2.5 Y 4/2) moist; clay; massive; firm; few, very fine to fine, vertical roots; gradual, smooth boundary; 17-19 cm thick; very weakly effervescent.
CK	86 +	Olive brown (2.5 Y 4/3) moist; sandy clay; massive; firm; few, fine, vertical roots; gradual, smooth boundary; weakly effervescent.

Site Description		
Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	3	gas well transect
Transect Position:	25m	
Plot:	C	
Slope Position:	Upper Slope	
Slope Gradient:	11%	Slope Class 5 - moderate slope
Slope Aspect:	353	North Northwest
Drainage Class:	4	Moderately Well Drained
Plant Community:	LF - e3.3	Aw-Sw-Pl/Labrador tea/hairy wild rye (p. 7-32)
Humus Form:	Fibrimor	
Microsite:	>60%, abundant, small, mild microrelief	
Parent Material:	Lacustro-till	

Horizon	Depth (cm)	Description
L	4 to 3	
F/H	3 to 0	Abundant, very fine and medium and plentiful, fine and coarse, horizontal roots.
Ae1	0 to 4	Brownish grey (10 YR 6/1) moist; silt clay loam; weak, coarse, platy, moderate, medium, platy; friable; plentiful, very fine to medium and few, coarse, horizontal, inped and exped roots; abrupt, wavy boundary; 3-8 cm thick.
Ae2	4 to 17	Brown (10 YR 4/6) moist; silty clay; very weak, medium, platy, moderate, fine, platy; very friable; plentiful, very fine and medium and few, fine and coarse, oblique, inped and exped roots; clear, wavy boundary; 9-13 cm thick.
Bt1	17 to 34	Dull yellowish brown (10 YR 5/3) moist; clay; very weak, fine, prismatic, moderate, fine, blocky; firm; plentiful, very fine to fine and few, medium, horizontal, inped and exped roots; clear, wavy boundary; 12-17 cm thick.
Bt2	34 to 63	Dull yellowish brown (10 YR 4/3) moist; clay; moderate, medium, prismatic, moderate, fine, blocky; very firm; few, very fine to coarse, vertical, exped roots; clear, smooth boundary; 25-30 cm thick.
Cca	63 +	Dark olive brown (2.5 Y 3/3) moist; clay; massive; firm; few, very fine to fine roots; gradual, smooth boundary; moderate to strongly effervescent.

Site Description		
Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	3	gas well transect
Transect Position:	75m	
Plot:	C	
Slope Position:	Middle Slope	
Slope Gradient:	8%	Slope Class 4 - gentle slope
Slope Aspect:	336	North Northwest
Drainage Class:	4	Moderately Well Drained
Plant Community:	LF - e3.6	Aw-Sw-Pl/feather moss (p. 7-46)
Humus Form:	Fibrimor	
Microsite:	30-60%, abundant, small, mild microrelief	
Parent Material:	Lacustro-till	

Horizon	Depth (cm)	Description
L	4 to 3	
F/H	3 to 0	Abundant, very fine and plentiful, fine to coarse, horizontal roots.
Ae1	0 to 9	Greyish yellow brown (10 YR 5/2) moist; silt clay loam; very weak, medium, blocky, strong, fine, platy; very friable; plentiful, very fine to fine and coarse and abundant, medium, horizontal, inped and exped roots; abrupt, wavy boundary; 5-9 cm thick.
Ae2	9 to 16	Yellowish brown (2.5 Y 5/4) moist; silt clay loam; very weak, fine, subangular blocky, strong, fine, platy; friable; plentiful, very fine to medium, horizontal, inped and exped roots; clear, wavy boundary; 6-14 cm thick.
AB	16 to 29	Dark greyish yellow (2.5 Y 5/2) dry; clay; weak, fine, prismatic, strong, fine, subangular blocky; hard; plentiful, very fine and few, fine to medium, vertical, exped roots; clear, wavy boundary; 10-12 cm thick.
Bt	29 to 56	Brownish black (2.5 Y 3/2) moist; clay; strong, medium, prismatic, weak, medium, subangular blocky; very firm; few, medium, vertical, exped roots; gradual, wavy boundary; 24-30 cm thick.
BCca	56 to 91	Dark olive brown (2.5 Y 3/3) moist; clay; weak, fine, prismatic, weak, fine, subangular blocky; very firm; few, medium, vertical, exped roots; gradual, smooth boundary; 34-42 cm thick; very weakly effervescent.
Cca	91 +	Brownish black (2.5 Y 3/2) moist; clay; massive; few, medium, horizontal roots; gradual, smooth boundary; weakly effervescent.

Site Description

Soil Classification:	Orthic Gray Luvisol (O. GL)	
Toposequence:	3	gas well transect
Transect Position:	125m	
Plot:	C	
Slope Position:	Toe	
Slope Gradient:	19%	Slope Class 6 - strong slope
Slope Aspect:	21	North Northeast
Drainage Class:	4	Moderately Well Drained
Plant Community:	LF - h1.1	Sb-Pl/Labrador tea/feather moss (p. 7-7)
Humus Form:	Fibrimor	
Microsite:	>60%, abundant, small, mild microrelief	
Parent Material:	Lacustro-till	

Horizon	Depth (cm)	Description
L	7 to 6	
F/H	6 to 0	Abundant, very fine to medium and plentiful, coarse roots.
Ae	0 to 8	Greyish yellow brown (10 YR 5/2) moist; silty clay; very weak, fine, subangular blocky, strong, medium, platy; firm; plentiful, very fine to medium and few, coarse, horizontal, inped and exped roots; abrupt, smooth boundary; 3-10 cm thick.
AB	8 to 21	Olive brown (2.5 Y 4/6) moist; silty clay; weak, coarse, platy, strong, medium, platy; firm; plentiful, very fine and few, fine to medium, horizontal, inped and exped roots; clear, wavy boundary; 9-13 cm thick.
Bt	21 to 72	Dull yellowish brown (10 YR 4/3) moist; clay; moderate, medium, prismatic, strong, medium, subangular blocky; very firm; few, very fine to fine, horizontal, exped roots; clear, wavy boundary; 48-51 cm thick.
BC	72 to 111	Olive brown (2.5 Y 4/2) moist; clay; very weak, medium, prismatic, strong, fine, subangular blocky; firm; gradual, smooth boundary; 39-48 cm thick; very weakly effervescent.
Ck	111 +	Dark olive brown (2.5 Y 3/3) moist; clay; very weak, fine, prismatic, moderate, fine, subangular blocky; firm; gradual, smooth boundary; weakly effervescent.

Site Description

Soil Classification:	Typic Mesisol (Ty. M)	
Toposequence:	3	gas well transect
Transect Position:	140m	
Plot:	C	
Slope Position:	Depression	
Slope Gradient:	0%	Slope Class 1 - level
Slope Aspect:	N/A	
Drainage Class:	7	Poorly Drained
Plant Community:	LF - h1.3	Sb-Pl/feather moss (p. 7-78)
Humus Form:	Mesic peatymor	
Microsite:	>60%, abundant, small, strong microrelief	
Parent Material:	Organic Soil	

Horizon	Depth (cm)	Description
L	0 to 1	
Om	1 to 91	Black (7.5 Y 2/1); few, very fine to coarse, horizontal roots; gradual, smooth boundary.
W/Om	90 +	

Site Description		
Soil Classification:	Typic Mesisol (Ty. M)	
Toposequence:	3	gas well transect
Transect Position:	275m	
Plot:	C	
Slope Position:	Depression	
Slope Gradient:	0%	Slope Class 1 - level
Slope Aspect:	N/A	
Drainage Class:	7	Poorly Drained
Plant Community:	LF - k1.1	Sb/Labrador tea/cloudberry/peat moss
Humus Form:	Mesic peatymor	
Microsite:	>60%, abundant, large, strong microrelief	
Parent Material:	Organic Soil	

Horizon	Depth (cm)	Description
Of	0 to 9	Light brown (7.5 YR 5/6); plentiful, very fine to medium and few, coarse, horizontal roots; clear, smooth boundary.
Om	9 to 89	Black (5 YR 2/1); abundant, very fine, plentiful, fine and few, medium to coarse horizontal roots; gradual, smooth boundary.

APPENDIX II

Ecological Response Variable and Soil Physical and Chemical Property Data.

Appendix 8. ERV & Mineral soil data.

Location Information				Slope Information			Dependent Variables: Leaf Area Index (m^2/m^2)			Tree Volume (m^3/ha)	Basal Area (m^2/ha)			Basal Area Increment ($m^2/ha/yr$)			Sapwood Area (m^2/ha)			Stand Density	
Toposequence Site	Transect Position	Plot	Slope Position	Slope Position	% slope	Aspect (°)	Grand Mean	LAI adj. BA	LAI adj. SA	Tree Volume	conifer	deciduous	Total	conifer	deciduous	Total	conifer	deciduous	Total	trees ha^{-1}	trees $10m^{-2}$
topo	trans	plot	slp_pos	slp_pos1	slp%	aspect	la	laiba	laisa	tre_vol	bac	bad	bat	baic	baid	bait	sac	sad	sat	sd_ha	sd_plot
1	35	C	1	crest	3	180	2.92	3.08	2.97	266.81	4.00	24.00	28.00	0.05	0.31	0.36	0.65	13.78	14.43	296.00	0.30
1	35	E	1	crest	3	180	2.00	2.00	2.00	405.57	0.00	40.00	40.00	0.00	0.48	0.48	0.00	21.87	21.87	520.00	0.52
1	35	W	1	crest	3	180	2.06	2.13	2.12	651.32	4.00	56.00	60.00	0.05	0.65	0.71	1.28	22.19	23.45	770.00	0.77
1	80	C	2	upper	16	176	2.16	2.38	2.30	329.91	9.00	25.00	34.00	0.12	0.31	0.43	2.64	13.54	16.38	477.25	0.48
1	80	E	2	upper	16	176	1.83	1.92	1.87	391.31	5.00	33.00	38.00	0.07	0.40	0.47	1.14	18.51	19.65	461.25	0.46
1	80	W	2	upper	16	176	1.91	2.05	2.01	569.16	10.00	44.00	54.00	0.14	0.51	0.65	2.59	17.60	20.19	1064.25	1.06
1	100	C	3	middle	23	202	2.22	2.53	2.46	393.02	14.00	26.00	40.00	0.18	0.32	0.50	5.03	13.29	18.32	658.50	0.66
1	100	E	3	middle	23	202	2.27	2.52	2.39	377.05	10.00	26.00	36.00	0.14	0.31	0.45	2.28	15.15	17.43	402.50	0.40
1	100	W	3	middle	23	202	2.75	3.12	3.00	466.99	16.00	32.00	48.00	0.22	0.37	0.59	3.92	13.01	16.93	1358.50	1.36
1	120	C	3	middle	19	212	2.62	3.05	2.99	456.13	19.00	27.00	46.00	0.25	0.32	0.57	7.23	13.04	20.27	839.75	0.84
1	120	E	3	middle	19	212	2.63	3.09	2.87	362.60	15.00	19.00	34.00	0.21	0.22	0.43	3.42	11.78	15.20	343.75	0.34
1	120	W	3	middle	19	212	3.25	3.93	3.75	404.82	22.00	20.00	42.00	0.31	0.23	0.54	5.25	8.43	13.67	1652.75	1.65
1	150	C	4	lower	13	210	3.64	4.31	4.26	519.24	24.00	28.00	52.00	0.32	0.32	0.64	9.42	12.79	22.21	1021.00	1.02
1	150	E	4	lower	13	210	3.51	4.39	4.00	348.54	20.00	12.00	32.00	0.28	0.13	0.42	4.56	8.42	12.98	285.00	0.29
1	150	W	4	lower	13	210	3.55	4.65	4.45	322.68	28.00	8.00	36.00	0.39	0.09	0.48	6.56	3.84	10.41	1947.00	1.95
1	180	C	4	lower	8	198	4.06	5.47	5.42	539.94	52.00	8.00	60.00	0.65	0.11	0.76	13.35	2.63	15.98	1818.00	1.82
1	180	E	4	lower	8	198	3.10	3.90	3.72	369.30	36.00	20.00	56.00	0.47	0.24	0.72	9.04	9.00	18.04	918.00	0.92
1	180	W	4	lower	8	198	4.34	5.79	5.58	480.07	40.00	8.00	48.00	0.54	0.10	0.64	9.67	3.87	13.54	1031.00	1.03
1	200	C	5	toe	3	208	3.68	4.80	4.79	329.00	32.00	10.00	42.00	0.46	0.20	0.66	9.05	3.00	12.04	2362.00	2.36
1	200	E	5	toe	3	208	3.50	4.41	4.45	367.74	26.00	14.00	40.00	0.43	0.12	0.55	9.56	4.50	14.06	817.50	0.82
1	200	W	5	toe	3	208	4.43	5.47	5.20	259.41	20.00	14.00	34.00	0.27	0.66	0.93	4.63	6.29	11.12	15370.00	15.37
2	12.5	C	1	crest	5	140	2.74	2.92	2.87	309.97	6.00	30.00	36.00	0.10	0.49	0.59	3.09	22.08	25.16	973.00	0.97
2	12.5	E	1	crest	5	140	2.88	3.46	3.39	241.25	14.00	14.00	28.00	0.23	0.22	0.45	9.58	12.26	21.84	812.00	0.81
2	12.5	W	1	crest	5	140	2.30	2.85	2.80	242.85	18.00	12.00	30.00	0.30	0.18	0.48	9.42	7.87	17.29	1118.00	1.12
2	50	C	2	upper	19	140	3.35	4.00	3.80	368.08	19.50	21.00	40.50	0.31	0.35	0.66	7.53	14.82	22.35	1040.50	1.04
2	50	E	2	upper	19	140	2.80	3.31	3.22	297.26	14.50	17.50	32.00	0.24	0.25	0.48	7.72	12.81	20.53	894.00	0.89
2	50	W	2	upper	19	140	3.16	3.84	3.70	290.48	19.50	16.50	36.00	0.31	0.27	0.58	8.42	11.48	19.88	1119.00	1.12
2	85	C	3	middle	26	138	3.55	4.58	4.41	426.16	33.00	12.00	45.00	0.52	0.20	0.73	11.86	7.57	19.53	1108.00	1.11
2	85	E	3	middle	26	138	2.91	3.40	3.27	353.27	15.00	21.00	36.00	0.25	0.27	0.52	5.87	13.35	19.22	578.00	0.58
2	85	W	3	middle	26	138	2.91	3.49	3.29	338.12	21.00	21.00	42.00	0.32	0.36	0.68	7.42	15.04	22.47	1120.00	1.12
2	85	C	5	toe	4	142	3.46	4.00	4.50	329.78	34.50	7.50	42.00	0.62	0.13	0.75	15.10	4.99	20.09	2789.00	2.79
2	85	E	5	toe	4	142	3.24	4.22	4.07	360.32	33.00	10.50	43.50	0.40	0.13	0.53	11.76	6.68	18.43	1499.00	1.50
2	85	W	5	toe	4	142	4.37	5.51	5.24	275.94	25.50	13.50	39.00	0.46	0.22	0.65	9.23	9.21	18.43	2670.50	2.67
3	10	C	1	crest	4	354	3.53	4.34	4.25	155.40	16.00	12.00	28.00	0.42	0.33	0.75	6.04	5.73	11.77	1994.00	1.99
3	10	E	1	crest	4	354	3.58	4.19	4.07	171.23	12.00	16.00	28.00	0.32	0.34	0.66	5.55	10.62	16.17	2127.00	2.13
3	10	W	1	crest	4	354	3.16	4.42	4.42	66.76	12.00	0.00	12.00	0.36	0.00	0.36	5.71	0.00	5.71	709.00	0.71
3	25	C	2	upper	11	353	3.16	3.56	3.51	196.75	10.00	20.00	30.00	0.26	0.41	0.67	3.47	9.13	12.60	1860.00	1.86
3	25	E	2	upper	11	353	3.02	3.49	3.45	240.53	14.00	22.00	36.00	0.35	0.38	0.73	6.65	12.09	18.73	3075.00	3.08
3	25	W	2	upper	11	353	3.01	3.85	3.70	127.24	14.00	6.00	20.00	0.38	0.10	0.48	5.24	3.96	9.19	1276.50	1.28
3	75	C	5	middle	8	336	2.77	2.91	2.84	238.11	4.00	28.00	32.00	0.09	0.50	0.59	0.91	12.53	13.44	1726.00	1.73
3	75	E	5	middle	8	336	3.10	3.55	3.55	309.84	16.00	28.00	44.00	0.36	0.42	0.80	7.75	13.55	21.30	4023.00	4.02
3	75	W	5	middle	8	336	3.52	4.32	4.05	187.72	16.00	12.00	28.00	0.42	0.20	0.62	4.77	7.91	12.68	1847.00	1.85
3	125	C	5	toe	19	4	3.46	4.84	4.84	240.67	48.00	0.00	48.00	1.13	0.00	1.13	14.78	0.00	14.78	8010.00	8.01
3	125	E	5	toe	19	4	2.15	3.01	3.01	136.59	20.00	0.00	20.00	0.32	0.00	0.32	7.24	0.00	7.24	755.00	0.76
3	125	W	5	toe	19	4	3.10	4.34	4.34	150.11	28.00	0.00	28.00	0.70	0.00	0.70	12.15	0.00	12.15	2596.00	2.60

Appendix 6. ERV & Mineral soil data.

Location Information				Forest Floor																	Forest Floor
				Forest Floor (cm)	Total Mineralized N (µg/g/2weeks) O.d basis				Total Forest Floor Avail. N (µg/cm²/2 weeks)	Total Forest Floor Avail. N (mg/m²/2 weeks) Data		Total %C of the Forest Floor (% by weight)	Total C of the Forest Floor Data (kg/m²)		Total %N of the Forest Floor Data (% by weight)	Total N of the Forest Floor Data (kg/m²)		(%)	Bulk Density (Db) Forest Floor Data (g/cm³)		
Toposequence Site	Transect Position	Plot	Slope Position	Hor/Thick. F/H or Org.	July 29-31 to 12-15 August	12-15 August to 28-29 August	Mean	Mean	Mean	Mean	Stdev	Mean	Mean Forest Floor Total Carbon	Stdev Forest Floor Total Carbon	Mean Forest Floor % Total Nitrogen	Mean Forest Floor Total Nitrogen	Stdev. Forest Floor Total Nitrogen	Forest Floor C/N	Mean Db Forest Floor	Stdev. Db Forest Floor	pHw FF
topo	trans	plot	slp_pos	ff_th	1ffmoving	2ffmoving	mffmoving	ff_nmanc	ff_nmonth			ff_percC	ff_C_h		ff_percN	ff_N_h		ff_cn	ff_db		ff_phw
1	35	C	1	8.00	31.78	33.16	32.46	4.11	328.80	10.18		42.13	4.27	0.37	1.90	0.19	0.013	22.18	0.13	0.01	6.11
1	35	E	1	6.00	30.43	-17.08	6.68	0.96	57.30	288.92		40.34	3.47	0.03	1.96	0.17	0.014	20.57	0.14	0.08	5.74
1	35	W	1	5.00	-93.08	-5.15	-49.41	0.64	32.00	91.22		41.44	2.07	0.08	2.10	0.11	0.008	19.71	0.10	0.01	6.55
1	80	C	2	4.00	10.35	-23.95	-6.80	-0.71	-26.20	100.41		34.64	1.43	0.35	1.76	0.07	0.010	19.66	0.10	0.03	6.60
1	80	E	2	10.00	26.55	-1.97	12.29	1.46	147.50	242.54		37.58	4.51	0.36	1.88	0.23	0.027	19.85	0.12	0.04	6.20
1	80	W	2	3.00	11.85	60.07	45.96	5.82	174.60	183.28		37.65	1.43	0.16	1.50	0.06	0.003	25.06	0.13	0.03	6.14
1	100	C	3	3.00		-0.75	-0.75	-0.09	-4.50			39.80	2.32	0.16	1.77	0.10	0.005	22.43	0.12	0.01	6.35
1	100	E	3	4.00	-2.77	181.42	89.32	-0.40	-16.00			41.44	2.38	0.05	1.93	0.11	0.008	21.43	0.14	0.06	6.31
1	100	W	3	3.00	29.98	61.03	45.20	3.63	108.75	53.25		36.67	0.88	0.15	1.60	0.04	0.006	22.97	0.08	0.02	6.11
1	120	C	3	10.00		21.68	21.68	2.60	260.00			39.48	4.74	0.55	1.66	0.20	0.014	23.73	0.12	0.06	6.70
1	120	E	3	4.00	-10.85	30.86	10.00	1.04	41.40	121.91		31.09	1.29	0.10	1.58	0.07	0.001	19.64	0.10	0.03	6.20
1	120	W	3	5.00	41.41	1.85	21.68	2.53	126.50	162.63		35.05	2.04	0.24	1.43	0.08	0.006	24.44	0.12	0.02	6.52
1	150	C	4	7.00	9.28	68.14	38.71	5.29	370.30	397.96		32.24	3.08	0.40	1.34	0.13	0.014	24.15	0.14	0.03	5.88
1	150	E	4	4.50	-6.98	-7.76	-7.37	-0.89	-39.83	2.86		34.92	1.69	0.18	1.43	0.06	0.009	24.39	0.12	0.02	5.37
1	150	W	4	4.00	208.22	10.65	109.44	1.03	41.20			40.27	1.36	0.25	1.38	0.05	0.007	29.19	0.10	0.01	
1	180	C	4	13.00	10.91	13.19	12.05	1.21	156.65	21.14		41.03	5.33	0.23	1.48	0.19	0.019	27.69	0.10	0.02	6.14
1	180	E	4	9.00	15.77	4.25	10.01	1.07	95.85	78.28		42.51	4.06	0.47	1.53	0.15	0.009	27.82	0.11	0.02	5.05
1	180	W	4	7.00		48.47	48.47	3.86	271.60			42.05	2.35	0.11	1.35	0.07	0.005	31.61	0.08	0.02	
1	200	C	5	8.00	32.60	34.02	33.31	4.00	319.60	9.62		40.53	3.89	0.25	1.59	0.15	0.006	25.51	0.12	0.03	5.91
1	200	E	5	7.00	25.47	-41.06	-7.80	-0.62	-43.40	263.33		42.44	2.38	0.07	1.53	0.09	0.009	27.76	0.08	0.02	6.55
1	200	W	5	10.50	-15.10	3.17	-5.96	-0.68	-70.88	153.69		39.30	4.68	0.98	1.52	0.18	0.036	25.77	0.11	0.05	5.70
2	12.5	C	1	2.00	41.18		41.18	3.98	79.60			38.35	0.74	0.02	1.43	0.03	0.002	26.85	0.10	0.02	
2	12.5	E	1	9.00	27.09	-54.61	-13.76	-1.06	-94.95	399.02		33.89	2.34	0.24	1.15	0.08	0.006	29.39	0.08	0.02	6.14
2	12.5	W	1	5.00	37.70	24.31	31.01	2.49	124.25	37.83		36.72	1.47	0.31	1.05	0.04	0.003	35.06	0.08	0.02	5.23
2	50	C	2	6.00	18.05	-48.20	-14.08	-1.08	-64.80	208.74		41.50	1.91	0.05	1.45	0.07	0.007	28.72	0.08	0.01	5.69
2	50	E	2	4.00	18.61	-5.04	6.89	0.51	20.20	49.50		40.90	1.20	0.06	1.31	0.04	0.007	31.27	0.07	0.03	5.77
2	50	W	2	5.00	6.07	-22.64	-8.28	-0.72	-35.75	86.03		43.78	1.90	0.22	1.46	0.06	0.005	29.91	0.09	0.02	5.38
2	65	C	3	6.00	-26.44	90.74	31.15	2.71	162.30	437.42		43.11	2.24	0.12	1.25	0.07	0.007	34.42	0.09	0.03	6.55
2	65	E	3	3.50	-24.81	58.21	16.70	1.51	82.78	290.31		35.65	1.78	0.51	1.15	0.06	0.005	31.06	0.09	0.02	6.40
2	65	W	3	3.50	32.22	22.29	27.26	1.62	100.10	25.67		44.81	1.64	0.01	1.27	0.05	0.007	35.16	0.07	0.02	5.69
2	85	C	5	9.00	36.80	55.49	46.15	3.69	332.10	95.46		41.21	2.97	0.21	1.49	0.11	0.015	27.62	0.08	0.04	4.72
2	85	E	5	4.00	30.45	5.74	18.09	2.05	82.00	79.20		43.66	1.98	0.17	1.31	0.06	0.011	33.35	0.11	0.03	5.63
2	85	W	5	8.00	-14.84	-7.09	-10.96	-0.81	-64.40	32.24		45.84	2.69	0.10	1.14	0.07	0.002	40.10	0.07	0.02	5.31
3	10	C	1	4.00	100.00	-4.52	47.74	3.02	120.80	167.24		47.02	1.19	0.02	1.52	0.04	0.004	30.84	0.06	0.01	
3	10	E	1	4.00	-18.80	-36.61	-27.60	-1.85	-74.00	33.94		47.07	1.26	0.04	1.80	0.05	0.005	26.12	0.07	0.01	4.77
3	10	W	1	5.00	-147.63	-111.50	-129.56	-8.21	-410.25	80.96		41.67	1.32	0.41	1.01	0.03	0.009	41.16	0.08	0.02	4.60
3	25	C	2	3.00	-0.55	147.42	73.44	7.10	213.00	303.35		43.22	1.25	0.13	1.72	0.05	0.011	25.11	0.10	0.02	4.10
3	25	E	2	2.00	61.11	53.05	67.08	4.92	98.40	28.13		45.13	0.66	0.03	1.59	0.02	0.002	28.47	0.07	0.02	5.31
3	25	W	2	3.50	531.16	75.90	303.54	8.07	212.45			44.15	1.24	0.08	1.60	0.04	0.004	27.64	0.06	0.01	5.50
3	75	C	3	3.00	857.15	1.56	429.35	0.15	4.50			44.43	1.29	0.08	1.94	0.06	0.001	22.96	0.10	0.02	5.75
3	75	E	3	6.00		0.88	0.88	0.07	5.60			42.05	1.87	1.63	1.58	0.11	0.015	26.59	0.06	0.03	5.61
3	75	W	3	7.00	55.72		55.72	4.83	338.10			46.25	2.81	0.10	1.75	0.11	0.005	26.40	0.09	0.01	5.20
3	125	C	5	6.00	7.55	49.06	28.30	1.51	90.60	94.19		48.16	1.54	0.03	1.24	0.04	0.003	36.66	0.05	0.02	4.91
3	125	E	5	14.00	-13.43	48.17	17.37	1.68	235.20	590.01		46.86	4.41	3.62	1.31	0.18	0.022	37.21	0.10	0.02	4.26
3	125	W	5	13.00	-66.90	-52.81	-60.86	-6.29	-817.70	152.59		48.30	6.49	0.09	1.29	0.17	0.032	37.33	0.10	0.06	5.48

Appendix II. DEV & Mineral soil data.

Location Information				Forest Floor				Forest Floor	A Horizon							A Horizon	
				Moisture Content (g 100g^{-1}) Forest Floor 29 to 31 July 1996		Moisture Content (g 100cm^{-2} or cm 100^{-1}) Forest Floor 29 to 31 July 1996	Moisture Content (g 100g^{-1}) 12 to 15 August 1996	Moisture Content (g 100cm^{-2} or cm 100^{-1}) Forest Floor 12 to 15 August 1996	(cm)						Total Mineralized N (µg/g/2weeks) O.d basis	(µg/cm^{3}/2weeks)
Toposequence Site	Transect Position	Plot	Slope Position	Mean MC% Forest Floor 29 to 31 July 1996	Stdev. MC% Forest Floor 29 to 31 July 1996	Soil Water (cm) 29 to 31 July 1996	MC% Forest Floor 12 to 15 August 1996	Soil Water (cm) 12 to 15 August 1996	Hor. Thick. A_1	Hor. Thick. A_2	Hor. Thick. Bm	Hor. Thick. A_3	Hor. Thick. AB	Whole A Hor. Thick.	A1	Total Avail N Min A_1 Horizon
topo	trans	plot	sp_pos	ffmc2931		ffw2931	ffmc1215	ffw1215	a1_h_th	a2_h_th	bm_h_th	a3_h_th	ab_h_th	a_th	a1nmng	a1_nmmc
1	35	C	1	70.71	6.80	71.65	69.84	70.77	11		7	10	7	35	-0.26	-0.4
1	35	E	1	99.39	26.42	85.46	62.87	71.27	10					34	1.14	1.5
1	35	W	1	83.96	4.84	41.99	108.48	54.24	11					35	3.04	3.7
1	60	C	2	61.66	1.26	25.49	68.17	28.18	6					6	2.16	2.7
1	60	E	2	69.33	13.60	99.99	77.47	92.96	11					11	1.48	1.4
1	60	W	2	47.96	5.01	16.22	44.65	17.04	10					10	3.29	3.7
1	100	C	3	102.66		59.69	112.96	65.91	8	7				15		
1	100	E	3	63.91	20.39	36.64	76.79	45.17	11					18		
1	100	W	3	76.71	3.24	16.41	115.99	27.84	11					18	0.26	0.3
1	120	C	3	93.25		111.90	112.50	135.00	9	5				14		
1	120	E	3	71.11	4.71	29.39	77.75	32.14	12					17	0.50	0.7
1	120	W	3	92.02	36.01	53.68	110.13	64.24	11					16	1.64	2.3
1	150	C	4	80.28	8.23	76.80	70.06	67.02	21				10	31	1.67	2.3
1	150	E	4	75.68	5.31	40.86	84.42	45.59	11					21	2.16	3.1
1	150	W	4	81.21		31.40	105.38	40.75	11					21	1.61	2.1
1	180	C	4	114.69	5.15	149.10	70.41	91.53	21					21		
1	180	E	4	94.89	4.61	91.09	109.55	105.17	11					11	0.29	0.4
1	180	W	4			0.00	121.07	67.80	12					12		
1	200	C	5	106.09	0.67	101.84	162.07	155.59	30					30	0.94	1.2
1	200	E	5	161.76	58.07	101.79	240.06	134.43	10					10	1.91	1.8
1	200	W	5	123.61	14.80	133.29	133.29	158.62	12					12	1.30	1.5
2	12.5	C	1	64.72		12.51		0.00	9		7	13		29		
2	12.5	E	1	116.35	32.99	60.26	129.65	69.46	11					31	3.82	3.4
2	12.5	W	1	136.22	161.07	54.49	54.54	21.82	11					31	1.58	2.1
2	50	C	2	57.08	9.05	26.26	54.50	25.07	5		9	8		22	2.38	2.4
2	50	E	2	66.72	13.58	19.57	69.66	20.43	11					28	1.04	1.0
2	50	W	2	88.66	1.15	36.42	83.03	35.98	12					29	0.11	0.1
2	65	C	3	52.57	15.03	27.33	40.34	20.98	11		13			24	0.33	0.4
2	65	E	3	61.94	4.40	30.66	51.39	25.44	11					24	2.45	2.3
2	65	W	3	33.46	11.55	19.60	36.79	20.62	10					23	1.23	1.4
2	85	C	5	84.38	15.40	60.75	62.55	45.04	13					13	-0.06	-0.1
2	85	E	5	54.35	23.63	24.64	47.68	21.61	11					11	0.95	0.9
2	85	W	5	67.00	18.69	38.30	96.20	57.61	10					10	0.25	0.3
3	10	C	1	79.57		20.16	95.72	24.25	6				13	19	0.06	0.1
3	10	E	1	52.34	7.70	13.96	57.15	15.24	11					24	0.29	0.3
3	10	W	1	96.56	24.02	30.58	69.70	31.57	10					23	2.71	3.2
3	25	C	2	84.53	22.93	24.51	69.24	20.08	4	13				17	1.73	2.2
3	25	E	2	51.08	21.65	7.49	55.59	8.15	11					24	0.61	0.6
3	25	W	2	62.02	13.22	22.87	131.79	36.60	11					24	-0.15	-0.2
3	75	C	3	49.35	46.75	14.31	69.91	20.27	9	7			13	29	-0.42	-0.6
3	75	E	3	57.17		36.11	97.92	65.26	11					31	2.59	3.4
3	75	W	3	61.43	10.80	49.40		0.00	10					30	0.01	0.0
3	125	C	5	103.74	17.96	33.20	73.65	23.57	8		13			21	-1.66	-2.2
3	125	E	5	85.14	35.69	115.22	101.96	136.01	11					24	0.09	0.1
3	125	W	5	81.41	12.45	109.35	81.23	109.12	11					24	-0.20	-0.3

Appendix 8. ERV & Mineral soil data.

Location information				A Horizon (mg/m²/2 weeks)		Total %C of the A horizon Data (% by weight)	Total Carbon of the Forest Floor Data (kg/m²)			Total %N of the A horizon Data (% by weight)	Total N of the Forest Floor Data (kg/m²)			(%)	Bulkdensity (Db) A Horizon Data (g/cm3)	
Toposequence Site	Transect Position	Plot	Slope Position	Total Avail N Min A_1 Horizon	Total Avail N Min Whole A Horizon	Mean	Mean A_1 Horizon	Stdev. A_1 Horizon	Mean Whole A Horizon	Mean	Mean A_1 Horizon	Stdev. A_1 Horizon	Mean Whole A Horizon	A horizon C/N	Mean	Stdev.
topo	trans	plot	slp_pos	a1_nminh	a_nminh	a_percC	a1_C_h		a_C_h	a_percN	a1_N_h		a_N_h	a_cn	a_db	
1	35	C	1	-39.6	-126.0	0.78	1.16	0.35	3.69	0.08	0.13	0.02	0.40	9.2	1.36	0.05
1	35	E	1	145.0	493.0	1.07	1.36	0.50	4.64	0.11	0.14	0.05	0.49	9.4	1.27	0.20
1	35	W	1	403.7	1284.5	1.05	1.39	0.32	4.42	0.10	0.13	0.02	0.40	11.0	1.21	0.10
1	60	C	2	163.2	163.2	1.34	1.01	0.14	1.01	0.14	0.10	0.02	0.10	9.9	1.26	0.16
1	60	E	2	151.8	151.8	3.20	3.27	2.00	3.27	0.28	0.28	0.18	0.28	11.5	0.93	0.23
1	60	W	2	369.0	369.0	1.73	1.94	0.40	1.94	0.14	0.15	0.01	0.15	12.7	1.12	0.09
1	100	C	3			1.12	1.15	0.26	2.15	0.11	0.11	0.02	0.21	10.3	1.26	0.14
1	100	E	3			2.02	2.32	1.61	3.87	0.16	0.19	0.09	0.31	12.3	1.10	0.26
1	100	W	3	36.3	59.4	1.52	1.92	0.70	3.15	0.12	0.15	0.02	0.24	12.9	1.15	0.10
1	120	C	3			0.74	0.89	0.21	1.39	0.08	0.10	0.02	0.16	8.8	1.34	0.13
1	120	E	3	60.4	113.9	1.46	1.98	0.64	2.61	0.13	0.18	0.04	0.25	11.2	1.13	0.06
1	120	W	3	257.4	374.4	0.86	1.21	0.14	1.75	0.09	0.12	0.02	0.17	10.1	1.27	0.19
1	150	C	4	460.9	709.9	0.74	2.12	1.11	3.13	0.07	0.20	0.04	0.29	10.6	1.37	0.18
1	150	E	4	544.3	657.3	0.83	1.32	0.30	2.52	0.09	0.14	0.03	0.27	9.2	1.45	0.06
1	150	W	4	228.8	436.8	0.76	1.08	0.32	2.07	0.08	0.11	0.02	0.20	10.1	1.29	0.04
1	180	C	4			2.89	6.47	2.35	6.47	0.16	0.35	0.07	0.35	18.5	1.07	0.17
1	180	E	4	40.7	40.7	1.64	2.29	1.43	2.29	0.13	0.18	0.07	0.18	12.8	1.27	0.20
1	180	W	4			0.82	1.25	0.37	1.25	0.08	0.12	0.02	0.12	10.4	1.33	0.08
1	200	C	5	357.0	357.0	1.70	6.50	3.06	6.50	0.12	0.46	0.14	0.46	14.0	1.28	0.15
1	200	E	5	182.0	182.0	3.84	3.64	0.94	3.64	0.26	0.24	0.06	0.24	15.0	0.95	0.15
1	200	W	5	160.0	160.0	3.45	4.77	1.97	4.77	0.22	0.30	0.09	0.30	15.9	1.15	0.17
2	12.5	C	1			1.20	1.14	0.10	3.67	0.06	0.08	0.01	0.25	14.8	1.05	0.04
2	12.5	E	1	369.6	1041.6	1.99	1.93	1.35	5.44	0.11	0.10	0.04	0.29	18.7	0.88	0.26
2	12.5	W	1	226.6	656.6	0.74	1.06	0.46	2.99	0.06	0.09	0.02	0.26	11.5	1.30	0.07
2	50	C	2	119.0	523.6	1.24	0.62	0.21	2.74	0.06	0.04	0.01	0.19	14.8	1.00	0.01
2	50	E	2	112.2	285.6	1.56	1.67	0.43	4.24	0.10	0.11	0.01	0.28	15.4	0.97	0.20
2	50	W	2	13.2	31.9	1.20	1.54	0.53	3.72	0.07	0.09	0.01	0.22	16.8	1.07	0.06
2	65	C	3	41.6	91.2	1.06	1.32	0.24	2.88	0.08	0.10	0.01	0.21	13.5	1.13	0.09
2	65	E	3	247.5	540.0	1.31	1.32	0.39	2.88	0.09	0.09	0.01	0.19	15.1	0.92	0.12
2	65	W	3	136.0	312.8	1.22	1.36	0.51	3.13	0.08	0.09	0.02	0.20	15.7	1.11	0.15
2	85	C	5	-11.7	-11.7	3.45	4.54	0.91	4.54	0.20	0.26	0.08	0.26	17.5	1.01	0.13
2	85	E	5	100.1	100.1	7.59	7.99	10.12	7.99	0.51	0.53	0.71	0.53	14.9	0.98	0.48
2	85	W	5	31.0	31.0	1.15	1.41	0.59	1.41	0.08	0.09	0.02	0.09	15.3	1.23	0.05
3	10	C	1	4.8	15.2	1.08	0.83	0.21	2.62	0.10	0.08	0.02	0.24	10.8	1.27	0.15
3	10	E	1	35.2	76.8	1.27	1.58	0.89	3.45	0.10	0.13	0.06	0.27	12.5	1.13	0.25
3	10	W	1	321.0	736.3	1.44	1.71	0.13	3.93	0.11	0.13	0.02	0.30	13.2	1.18	0.04
3	25	C	2	87.2	370.6	0.74	0.38	0.11	1.60	0.06	0.04	0.01	0.16	9.8	1.26	0.11
3	25	E	2	83.6	182.4	1.13	1.54	1.03	3.37	0.07	0.10	0.02	0.22	15.6	1.25	0.16
3	25	W	2	-20.0	-44.7	0.62	1.12	0.25	2.51	0.07	0.10	0.01	0.23	11.1	1.30	0.16
3	75	C	3	-32.2	-168.2	0.60	0.98	0.27	3.17	0.08	0.09	0.01	0.30	10.4	1.37	0.06
3	75	E	3	352.8	1024.8	0.81	1.10	0.31	3.20	0.07	0.09	0.01	0.27	11.7	1.30	0.07
3	75	W	3	1.0	3.0	0.74	0.99	0.07	2.98	0.07	0.10	0.01	0.30	9.9	1.34	0.04
3	125	C	5	-176.0	-462.0	1.05	1.12	0.57	2.93	0.07	0.08	0.02	0.21	14.2	1.33	0.13
3	125	E	5	13.2	28.8	2.67	3.73	3.56	6.13	0.14	0.19	0.13	0.41	19.7	1.27	0.38
3	125	W	5	-37.4	-81.6	1.45	1.87	0.33	4.08	0.10	0.13	0.01	0.29	14.2	1.18	0.28

Appendix II. ERV & Mineral soil data.

Location Information				A Horizon: Particle Size Distribution (% by weight)			pHw Data	(meq/100g)	Moisture Content (g 100g^{-1})	Moisture Content (g 100cm^{-2} or cm 100^{-1}) A horizon 29 to 31July 1998	Moisture Content (g 100g^{-1}) A Horizon 7 to 13 October 1998	Moisture Content (g 100cm^{-2} or cm 100^{-1}) A horizon 7 to 13 October 1998	A Horizon: Estimated Field Capacity A Horizon	
Toposequence Site	Transect Position	Plot	Slope Position	%clay A Horizon	%silt A Horizon	%sand A Horizon	Mean pHw A	CEC	A Horizon 29 to 31 July 1998	Soil Water (cm) 29 to 31 July 1998	Mean MC% A horizon 7 to 13 October 1998	Soil Water (cm) 7 to 13 October 1998	(g 100g^{-1})	(g 100cm^{-2})
topo	trans	plot	slp_pos	a_clay	a_silt	a_sand	a_phw	a_cec	a_mc2931	aew2931	a_mc713	aew713	a_fc	a_fc_h
1	35	C	1	8.49	67.38	24.14	5.61	6.39			11.80	564.89	23.77	1128.45
1	35	E	1	14.02	58.96	27.02	6.57	8.85	12.90	557.02	22.81	984.94	24.10	1040.75
1	35	W	1	8.81	64.03	27.17	5.91	6.54	7.10	299.86	17.04	719.68	23.02	972.34
1	80	C	2	14.30	52.43	33.26	6.20	9.08	17.31	130.86	20.47	154.75	22.49	170.06
1	80	E	2	13.10	55.32	31.58	5.83	8.52	13.67	139.84	26.76	273.75	22.70	232.27
1	80	W	2	12.79	43.09	44.13	6.20	8.36	11.86	132.83	29.44	329.73	19.31	216.23
1	100	C	3	9.67	43.70	46.63	6.01	6.93			17.90	343.58	18.01	345.86
1	100	E	3	13.97	55.85	30.18	6.16	8.93			22.21	426.25	23.25	446.22
1	100	W	3	12.51	29.31	58.18	5.85	8.25	13.95	287.93	98.47	2032.42	15.51	320.12
1	120	C	3	11.42	56.70	31.88	6.28	7.75			15.83	296.14	22.29	417.11
1	120	E	3	17.87	48.28	34.05	5.33	10.64	15.99	308.07	9.75	187.85	22.96	442.38
1	120	W	3				5.03		12.55	255.69	17.29	352.25	1.88	38.37
1	150	C	4	13.26	66.90	19.84	5.64	8.80	10.66	452.73	12.04	511.34	25.86	1098.27
1	150	E	4	10.32	43.89	45.78	5.22	7.24	12.73	388.52	21.12	644.58	18.37	560.60
1	150	W	4	10.60	64.45	24.95	6.21	7.37	8.39	227.67	10.79	293.06	23.97	650.99
1	180	C	4	10.22	63.10	26.67	6.47	7.19			13.01	291.42	23.43	524.89
1	180	E	4	10.98	60.33	28.69	6.60	7.54	16.75	234.61	18.95	265.43	23.05	322.85
1	180	W	4	12.28	61.56	26.16	5.99	8.14			5.14	78.42	23.98	365.89
1	200	C	5	11.60	63.45	24.95	6.28	7.83	15.69	600.93	15.75	603.25	24.17	925.66
1	200	E	5	9.98	57.24	32.78	6.64	7.08	37.97	360.72	16.37	155.52	21.76	206.74
1	200	W	5	22.39	56.27	21.34	6.81	12.82	22.20	307.19	19.35	267.03	27.29	376.54
2	12.5	C	1	6.17	48.77	45.05	5.32	5.52			7.89	240.66	17.73	541.69
2	12.5	E	1	5.76	46.49	47.75	5.29	5.13	12.43	339.09	16.57	506.59	16.94	462.00
2	12.5	W	1	4.23	46.29	49.29	4.58	4.42	9.85	396.96	17.34	698.60	16.17	651.03
2	50	C	2	10.65	52.88	36.47	5.44	7.39	7.07	155.54	15.17	333.63	20.91	460.11
2	50	E	2	5.87	65.96	28.17	5.30	5.18	9.07	247.19	20.67	563.33	22.17	604.11
2	50	W	2	5.04	57.27	37.69	4.27	4.80	16.98	528.53	23.35	726.81	19.47	605.97
2	65	C	3	7.42	36.87	55.71	4.97	5.90	5.28	143.19	21.34	578.74	15.15	410.88
2	65	E	3	4.42	31.50	64.09	5.32	4.51	13.60	300.29	17.77	392.36	12.32	272.10
2	65	W	3	5.90	53.02	41.08	4.71	5.19	7.93	203.06	20.21	517.51	16.74	429.82
2	85	C	5	15.79	53.51	30.71	6.16	9.77	19.56	257.67	23.07	303.91	23.48	309.26
2	85	E	5	20.09	51.57	28.36	5.53	11.78	18.84	198.26	10.74	113.02	24.86	262.70
2	85	W	5	9.7	59.8	30.5	4.19	6.95	20.59	253.26	22.65	278.60	22.31	274.44
3	10	C	1	12.13	59.97	27.90	5.36	8.07	15.44	373.55	13.47	325.88	23.49	568.29
3	10	E	1	6.01	64.97	29.03	5.45	5.24	9.19	249.23	20.48	555.42	21.87	595.78
3	10	W	1	14.01	56.77	29.22	5.50	8.94	18.67	508.14	9.27	252.30	23.51	639.96
3	25	C	2	7.34	67.09	25.57	5.31	5.86	10.79	231.73	17.90	384.43	23.15	497.23
3	25	E	2	7.91	63.75	28.34	5.17	6.12	11.92	356.85	16.10	481.71	22.53	674.07
3	25	W	2	7.45	57.77	34.77	5.50	5.91	20.59	630.84	19.32	591.74	20.72	634.74
3	75	C	3	9.35	57.03	33.62	5.60	6.79	22.65	697.70	18.39	728.66	21.41	646.64
3	75	E	3	7.64	55.99	36.37	5.06	6.00	12.19	462.09	21.45	848.31	20.34	804.37
3	75	W	3	8.80	59.80	31.40	5.06	6.53	13.59	546.32	12.58	505.72	21.69	880.10
3	125	C	5	16.93	61.56	1.51	5.02	10.29	42.51	1184.33	20.62	580.05	31.47	876.76
3	125	E	5	13.44	61.87	24.69	6.21	8.66	18.37	558.45	26.93	818.67	24.61	748.01
3	125	W	5	14.92	54.14	30.93	5.35	9.36	37.91	1070.58	20.28	572.71	23.24	656.26

Appendix 8. ERV & Mineral soil data.

Location Information				A Horizon		A Horizon		B Horizon						B Horizon		
				Estimated Permanent Wilting Point A Horizon		A Horizon Estimated Avail. Water Capacity		B-horizon (cm)	B-horizon (cm)			Total %C of the B horizon Data (% by weight)		Total C of the Forest Floor Data (kg/m²)		
Toposequence Site	Transect Position	Plot	Slope Position	(g 100g⁻¹)	(g 100cm⁻³)	(g 100g⁻¹)	(g 100cm⁻³)	Hor. Thick. B1	Hor. Thick. B2	Hor. Thick. BC	Whole B Hor. Thick.	B_1 Horizon	B_2 Horizon	Mean B_1 Horizon	Other (minor) B Horizons	Whole B Horizon
toposi	transe	plot	slp_pos	a_pwp	a_pwp_h	a_awc	a_awc_h	b1_h_th	b2_h_th	bc_h_th	b_th	b1_percC	b2_percC	b1_C_h	b2_C_h	b_C_h
1	35	C	1	7.59	360.43	16.17	768.02	27		13	40	0.502		2.11	1.02	3.13
1	35	E	1	8.71	375.89	15.40	664.66					0.839		2.66	1.28	3.94
1	35	W	1	7.46	315.14	15.56	657.20					0.878		3.72	1.79	5.51
1	60	C	2	6.35	63.12	14.15	106.94	48		42	90	0.841		4.92	4.31	9.23
1	60	E	2	6.18	83.67	14.53	148.59					0.860		4.83	4.23	9.06
1	60	W	2	7.26	81.31	12.05	134.93					0.544		3.97	3.47	7.44
1	100	C	3	6.35	121.93	11.66	223.94	48		24	72	0.503		3.26	1.64	4.93
1	100	E	3	8.48	162.74	14.77	283.48					0.876		5.80	2.90	8.70
1	100	W	3	6.24	128.68	9.27	191.24					0.457		3.40	1.70	5.10
1	120	C	3	7.76	145.25	14.53	271.68	27		33	60	0.857		3.75	4.58	8.33
1	120	E	3	9.09	175.22	13.87	267.18					0.858		2.70	3.30	6.00
1	120	W	3	0.48	9.36	1.42	29.01					0.628		2.19	2.67	4.86
1	150	C	4	9.01	382.64	16.85	715.63	31		26	57	0.817		3.88	3.25	7.13
1	150	E	4	6.56	200.27	11.81	360.33					0.537		2.35	1.87	4.32
1	150	W	4	8.03	218.23	15.93	432.76					0.811		2.77	2.32	5.08
1	180	C	4	7.63	175.35	15.60	349.54	40		19	59	0.568		3.15	1.49	4.64
1	180	E	4	7.67	110.27	15.18	212.56					0.537		2.49	1.18	3.68
1	180	W	4	8.35	127.41	15.63	238.49					0.549		3.36	1.60	4.96
1	200	C	5	8.27	316.60	15.90	608.65	39		27	66	0.504		2.91	2.01	4.92
1	200	E	5	7.36	69.92	14.40	136.62					0.736		4.63	3.21	7.84
1	200	W	5	11.07	152.77	16.22	223.76					1.322		7.84	5.43	13.26
2	12.5	C	1	5.63	171.94	12.10	369.75	34	52		86	0.397	0.415	2.23	2.33	4.56
2	12.5	E	1	5.35	145.95	11.59	316.05					0.398		2.27	3.48	5.75
2	12.5	W	1	4.67	196.30	11.30	455.33					0.424		2.09	3.20	5.29
2	50	C	2	7.27	159.92	13.64	300.16	45	48		93	0.465	0.492	2.86	2.92	5.80
2	50	E	2	6.70	182.53	15.47	421.56					0.539		3.76	4.01	7.77
2	50	W	2	5.86	182.36	13.61	423.62					0.572		4.12	4.39	8.51
2	85	C	3	5.21	141.18	9.94	269.66	14	53		67	0.420	0.419	0.83	0.83	1.67
2	85	E	3	3.93	86.79	8.39	185.31					0.376		0.77	2.93	3.70
2	85	W	3	5.83	149.37	12.90	330.45					0.266		0.53	2.02	2.55
2	85	C	5	8.88	116.92	14.60	192.34	28			28	0.760		3.45	0.00	3.45
2	85	E	5	10.05	105.79	14.91	156.91					0.983		4.29	0.00	4.29
2	85	W	5	7.45	91.60	14.67	182.84					0.687		2.82	0.00	2.82
3	10	C	1	8.20	198.34	15.29	369.96	22	26	17	67	0.481		1.44	2.95	4.39
3	10	E	1	6.67	160.98	15.30	414.80					0.521		1.79	3.66	5.45
3	10	W	1	8.55	232.81	14.96	407.17					0.553		1.86	3.81	5.67
3	25	C	2	7.22	155.09	15.93	342.15	17	29		46	0.623		1.47	2.51	3.98
3	25	E	2	7.17	214.50	15.38	459.57					0.764		2.04	3.48	5.52
3	25	W	2	6.69	202.93	14.10	431.81					0.404		1.02	1.73	2.75
3	75	C	3	7.15	283.53	14.26	565.11	27		55	82	0.769		3.09	4.01	7.10
3	75	E	3	6.56	259.56	13.76	544.80					0.737		2.91	3.77	6.67
3	75	W	3	7.17	286.37	14.72	591.73					0.667		2.88	3.74	6.62
3	125	C	5	11.12	309.68	20.35	567.07	51		39	90	0.894		7.30	5.58	12.87
3	125	E	5	8.72	265.24	15.88	482.77					0.812		6.13	4.69	10.82
3	125	W	5	8.65	244.37	14.59	411.89					2.147		17.41	13.31	30.72

Appendix E. EEV & Mineral soil data.

Location Information				B Horizon													B Horizon	
				Total %N of the B horizon Data (% by weight)		Total N of the Forest Floor Data (kg/m²)			(%)	Bulk Density (Db; g/cm³)	Particle Size Distribution (% by weight)				(meq/100g)	(g 100g⁻¹)	Moisture Content (g 100cm⁻³ or cm 100⁻¹) B horizon 7 to 13 October 1998
Toposequence Site	Transect Position	Plot	Slope Position	B_1 Horizon	B_2 Horizon	B_1 Horizon	Other (mineral) B Horizon	Whole B Horizon	B horizon C/N	Db B Horizon	%clay B Horizon	%silt B Horizon	%sand B Horizon	pHw B	CEC	MC% B Horizon 7 to 13 October 1998	Soil Water (cm) 7 to 13 October 1998
toso	trans	plot	slp_pos	b1_perN	b2_perN	b1_N_h	b2_N_h	b_N_h	b_cn	b_db	b_clay	b_silt	b_sand	b_pHw	b_cec	b_mc713	bsw713
1	35	C	1	0.081		0.34	0.16	0.51	6.2	1.56	39.02	40.69	20.30	4.74	20.51	13.85	864.24
1	35	E	1	0.112		0.47	0.22	0.69	5.7	1.54	45.86	35.94	18.19	5.30	25.67	25.28	1557.25
1	35	W	1	0.117		0.50	0.24	0.73	7.5	1.57	66.69	26.63	6.69	5.05	33.31	18.78	1176.13
1	60	C	2	0.105		0.81	0.71	1.51	6.1	1.60	46.25	31.72	22.03	5.29	23.65	18.2	2620.60
1	60	E	2	0.102		0.72	0.63	1.36	6.7	1.48	42.56	32.92	24.53	5.39	22.15		
1	60	W	2	0.092		0.67	0.59	1.26	5.9	1.52	33.76	34.21	32.04	5.33	16.06	11.15	1525.32
1	100	C	3	0.084		0.55	0.27	0.82	6.0	1.38	36.40	31.03	32.58	5.57	19.30	13.45	1317.02
1	100	E	3	0.128		0.85	0.42	1.27	6.6	1.36	65.34	27.03	7.63	5.49	32.68	22.74	2259.45
1	100	W	3	0.082		0.61	0.31	0.92	5.6	1.55	34.23	33.15	32.62	5.46	18.30	12.33	1376.03
1	120	C	3	0.122		0.53	0.65	1.19	7.0	1.62	66.13	24.36	9.51	5.79	33.05	13.46	1306.31
1	120	E	3	0.096		0.40	0.49	0.89	6.7	1.52	45.62	24.03	30.35	5.91	23.56	27.76	2539.54
1	120	W	3	0.094		0.33	0.40	0.73	6.7	1.29	46.94	33.00	16.06	5.12	24.17	8.67	671.06
1	150	C	4	0.107		0.51	0.43	0.93	7.6	1.53	33.76	34.29	31.95	5.38	18.06	16.56	1444.20
1	150	E	4	0.088		0.38	0.32	0.71	6.1	1.41	40.75	41.50	17.67	5.16	21.31	15.46	1242.52
1	150	W	4	0.087		0.39	0.33	0.72	7.0	1.46	61.98	20.76	17.26	5.65	31.13	6.05	503.46
1	180	C	4	0.060		0.44	0.21	0.66	7.1	1.39	32.94	40.95	26.11	6.23	17.70	10.11	829.12
1	180	E	4	0.074		0.34	0.16	0.51	7.3	1.16	52.64	43.06	24.31	5.64	17.56	16.37	1120.36
1	180	W	4	0.080		0.49	0.23	0.72	6.0	1.53	37.16	45.92	16.90	6.29	19.66	9.09	820.55
1	200	C	5	0.080		0.46	0.32	0.76	6.3	1.48	33.11	36.24	30.65	5.76	17.76	9.83	980.19
1	200	E	5	0.093		0.56	0.40	0.99	7.9	1.61	34.41	54.79	10.80	5.66	16.36	22.61	2402.54
1	200	W	5	0.089		0.53	0.37	0.89	14.9	1.52	35.56	44.66	19.54	6.13	16.92	22.2	2227.10
2	12.5	C	1	0.063	0.08	0.35	0.54	0.89	6.3	1.65	38.91	26.44	34.64	5.24	20.46	13.34	1692.95
2	12.5	E	1	0.062		0.35	0.54	0.90	6.4	1.68	36.69	29.20	34.11	5.06	19.43	12.37	1787.22
2	12.5	W	1	0.058		0.29	0.44	0.72	7.3	1.45	29.35	32.34	38.31	5.31	16.04	17.4	2169.78
2	50	C	2	0.076	0.07	0.45	0.48	0.93	6.4	1.32	41.38	48.48	10.13	5.07	21.61	3.66	449.30
2	50	E	2	0.082		0.57	0.61	1.18	6.6	1.55	51.98	44.77	3.24	4.95	26.51	20.24	2917.60
2	50	W	2	0.067		0.48	0.51	1.00	8.5	1.60	30.00	40.57	29.43	5.15	16.34	13.22	1967.14
2	65	C	3	0.066	0.07	0.13	0.50	0.63	6.4	1.42	26.66	36.80	36.52	5.21	14.80	14.53	1382.38
2	65	E	3	0.067		0.14	0.52	0.66	5.6	1.47	29.65	44.23	25.92	4.27	16.27	10.55	1039.07
2	65	W	3	0.054		0.11	0.41	0.51	5.0	1.42	26.39	30.96	42.65	5.30	14.67	14.8	1417.59
2	85	C	5	0.079		0.36	0.00	0.36	9.8	1.62	16.80	52.52	28.68	7.59	11.07	21.75	966.56
2	85	E	5	0.095		0.41	0.00	0.41	10.3	1.56	31.60	43.24	25.17	6.14	17.06	23.91	1044.39
2	85	W	5	0.075		0.32	0.00	0.32	8.9	1.51	32.19	42.64	25.17	4.74	17.35	16.56	764.72
3	10	C	1	0.070		0.22	0.45	0.67	6.6	1.42	42.34	30.68	26.97	5.03	22.05	19.09	1816.22
3	10	E	1	0.068		0.24	0.48	0.72	7.6	1.56	36.06	32.94	30.98	5.23	19.15	14.48	1513.45
3	10	W	1	0.067		0.29	0.60	0.89	6.4	1.53	34.21	29.15	16.64	4.63	27.54	22.67	2323.90
3	25	C	2	0.079		0.19	0.32	0.51	7.9	1.39	42.48	35.19	22.33	5.11	22.11	15.03	961.02
3	25	E	2	0.077		0.21	0.35	0.56	9.9	1.57	38.40	28.94	31.65	5.23	20.69	13.25	856.82
3	25	W	2	0.065		0.16	0.28	0.44	6.2	1.48	36.26	29.10	34.63	5.17	19.23	19.73	1343.22
3	75	C	3	0.113		0.45	0.59	1.04	6.6	1.49	60.07	29.13	10.79	6.50	30.25	22.96	2121.04
3	75	E	3	0.105		0.41	0.54	0.95	7.0	1.46	61.42	23.80	14.78	4.69	30.67	20.23	1631.22
3	75	W	3	0.093		0.40	0.52	0.92	7.2	1.60	49.30	38.69	12.00	5.51	25.27	11.78	1166.56
3	125	C	5	0.105		0.66	0.66	1.31	8.5	1.60	50.44	36.30	13.26	6.73	25.79	21.07	3094.06
3	125	E	5	0.109		0.82	0.63	1.45	7.4	1.48	63.35	24.29	12.36	6.21	31.76	26.93	3587.08
3	125	W	5	0.068		0.55	0.42	0.97	31.6	1.39	34.45	55.57	9.98	8.32	18.40	21.38	3056.62

Appendix 8. EFV & Mineral soil data.

Location Information				B Horizon				B Horizon		C Horizon							C Horizon
				Estimated Field Capacity B Horizon		Estimated Permanent Wilting Point B Horizon		B horizon Estimated Avail. Water Capacity		(cm)			%C of the C horizon Data (% by weight)				
Toposequence Site	Transect Position	Plot	Slope Position	(g 100g^{-1})	(g 100cm^{-3})	(g 100g^{-1})	(g 100cm^{-3})	(g 100g^{-1})	(g 100cm^{-3})	Hor. Thick. C_1	Hor. Thick. C_2	Whole C Hor. Thick.	Total %C of C_1 horizon	Total %C of C_2 horizon	Organic %C of C_1 horizon	Organic %C of C_2 horizon	
topo	trans	plot	slp_pos	b_fc	b_fc_h	b_pwp	b_pwp_h	b_awc	b_awc_h	c1_h_th	c2_h_th	c_th	TC1_percC	TC2_percC	OC1_percC	OC2_percC	
1	35	C	1	30.88	1927.34	10.44	651.34	20.45	1276.00	40		40	0.962		0.759		
1	35	E	1	32.61	2021.20	11.78	725.36	21.04	1295.90								
1	35	W	1	40.04	2514.56	13.23	830.71	26.81	1683.86								
1	80	C	2	31.67	4580.39	13.70	1972.98	18.17	2616.40	19		19	0.590		0.572		
1	80	E	2	30.47	4058.62	12.94	1723.75	17.53	2335.07								
1	80	W	2	26.71	3654.56	16.17	2211.47	10.55	1443.08								
1	100	C	3	27.10	2053.50	17.10	1674.88	9.99	978.62	28		28	0.556		0.535		
1	100	E	3	30.52	3026.50	14.05	1390.26	25.47	2530.30								
1	100	W	3	28.65	2974.32	20.47	2264.73	6.18	689.59								
1	120	C	3	39.18	3607.94	14.62	1421.37	24.55	2386.57	41		41	0.550		0.554		
1	120	E	3	29.53	2883.34	13.90	1267.60	15.63	1425.74								
1	120	W	3	33.07	2559.29	3.83	280.79	29.44	2278.50								
1	150	C	4	28.74	2331.64	6.77	765.26	17.98	1566.37	27		27	0.511		0.472		
1	150	E	4	31.93	2566.60	17.14	1377.51	14.80	1189.10								
1	150	W	4	38.28	3019.63	12.23	1016.15	24.05	2001.48								
1	180	C	4	28.13	2306.56	10.80	885.53	17.33	1421.08	35		35	1.033		0.550		
1	180	E	4	28.55	1953.77	11.39	779.66	17.16	1174.09								
1	180	W	4	31.42	2856.59	10.83	986.54	20.49	1850.05								
1	200	C	5	26.95	2632.65	10.29	1004.73	16.67	1627.92	19		19	1.232		0.454		
1	200	E	5	32.49	3452.66	12.76	1355.46	19.74	2097.20								
1	200	W	5	30.40	3049.85	9.35	938.41	21.05	2111.44								
2	12.5	C	1	27.05	3838.31	16.79	2383.00	10.26	1455.32						0.409		
2	12.5	E	1	26.75	3864.30	17.48	2523.34	9.28	1341.05								
2	12.5	W	1	24.16	3013.04	17.44	2174.54	6.72	838.51								
2	50	C	2	34.07	4181.95	14.35	1761.60	19.72	2420.35								
2	50	E	2	38.02	5480.29	12.54	1807.63	25.48	3672.65								
2	50	W	2	26.65	3966.22	13.95	2076.12	12.70	1890.10								
2	65	C	3	24.10	2293.33	19.21	1827.77	4.89	465.57	24		24					
2	65	E	3	27.56	2714.24	21.86	2154.33	5.58	549.91								
2	65	W	3	22.42	2132.66	14.74	1402.39	7.68	730.27								
2	85	C	5	24.52	1112.35	11.06	501.65	13.46	610.70	45	29	74	1.143	0.845	0.509	0.340	
2	85	E	5	28.11	1227.67	11.22	490.16	16.89	737.71								
2	85	W	5	28.22	1199.32	11.81	503.65	16.31	689.67								
3	10	C	1	29.77	2832.62	11.81	1123.27	17.87	1709.35	29		29	0.512		0.477		
3	10	E	1	27.46	2869.88	11.73	1225.79	15.73	1644.09								
3	10	W	1	34.90	3577.26	13.01	1333.58	21.89	2243.68								
3	25	C	2	31.04	1984.58	11.11	710.16	19.93	1274.40	52		52	0.705		0.674		
3	25	E	2	27.94	2017.66	11.74	848.00	16.20	1169.85								
3	25	W	2	26.52	1805.48	13.49	918.16	13.03	887.32								
3	75	C	3	37.62	3475.50	14.74	1362.01	22.88	2113.49	24		24	0.739		0.562		
3	75	E	3	36.83	3334.10	15.67	1418.58	21.16	1915.52								
3	75	W	3	35.15	3486.59	13.34	1323.45	21.81	2163.14								
3	125	C	5	35.04	5046.10	4.32	622.57	30.72	4423.53	4		4	1.232		0.627		
3	125	E	5	37.88	5043.27	12.25	1631.41	25.61	3411.86								
3	125	W	5	32.72	4682.05	12.20	1745.23	20.52	2936.82								

Appendix 1 EPV & Mineral soil data.

Location Information				C Horizon													C Horizon		
				Organic C of the Forest Floor Data (kg/m2)			Total %N of the C horizon Data (% by weight)		Total N of the Forest Floor Data (kg/m^2)			(%)	C_1 Horizon Inorganic %C		Bulk Density (Db; g/cm^3)	Particle Size Distribution (% by weight)		
Toposequence Site	Transect Position	Plot	Slope Position	C_1 Horizon	Other (minor) C Horizons	Whole C Horizon	C_1	C_2	C_1 Horizon	Other (minor) C Horizon	Whole C Horizon	C horizon C/N	(g 100g^{-1})	(kg/m^2)	Db C Horizon	%clay C Horizon	%silt C Horizon	%sand C Horizon
Topo	trans	plot	slp_pos	OC1_C_h	OC2_C_h	OC_C_h	C1_percN	C2_percN	C1_N_h	C2_N_h	C_N_h	c_cn	IOC1	IOC1_h	c_db	c_clay	c_silt	c_sand
1	35	C	1	4.367		4.367	0.105		0.609	0.00	0.61	7.2	0.209	121.220	1.45	55.21	34.78	10.02
1	35	E	1															
1	35	W	1															
1	60	C	2	1.945		1.945	0.091		0.309	0.00	0.31	6.5	0.016	6.122	1.79	41.72	29.82	28.37
1	60	E	2															
1	60	W	2															
1	100	C	3	2.786		2.786	0.083		0.432	0.00	0.43	6.4	0.021	10.937	1.66	35.09	30.34	34.57
1	100	E	3															
1	100	W	3															
1	120	C	3	3.793		3.793	0.080		0.548	0.00	0.55	6.9	-0.004	-2.739	1.67	38.98	33.10	27.84
1	120	E	3															
1	120	W	3															
1	150	C	4	2.179		2.179	0.081		0.374	0.00	0.37	5.8	0.039	18.006	1.71	38.19	35.06	25.75
1	150	E	4															
1	150	W	4															
1	180	C	4	2.772		2.772	0.069		0.318	0.00	0.32	8.7	1.383	697.032	1.44	20.21	63.84	16.53
1	180	E	4															
1	180	W	4															
1	200	C	5	1.237		1.237	0.072		0.205	0.00	0.21	6.0	0.798	227.490	1.50	28.72	45.84	25.44
1	200	E	5															
1	200	W	5															
2	12.5	C	1												1.71	36.79	28.44	34.64
2	12.5	E	1															
2	12.5	W	1															
2	50	C	2												1.46	38.67	36.19	24.14
2	50	E	2															
2	50	W	2															
2	65	C	3												1.31	40.10	38.22	20.68
2	65	E	3															
2	65	W	3															
2	85	C	5	3.802	2.540	6.342	0.054	0.053	0.403	0.40	0.80	9.4	0.034	475.598	1.68	26.78	33.05	40.17
2	85	E	5															
2	85	W	5															
3	10	C	1	2.565		2.565	0.062		0.307	0.00	0.31	7.7	0.035	17.357	1.71	33.73	29.30	36.68
3	10	E	1															
3	10	W	1															
3	25	C	2	5.117		5.117	0.074		0.562	0.00	0.56	9.1	0.031	23.535	1.46	38.60	34.50	26.70
3	25	E	2															
3	25	W	2															
3	75	C	3	2.252		2.252	0.068		0.273	0.00	0.27	8.3	0.177	70.942	1.67	36.76	35.62	27.62
3	75	E	3															
3	75	W	3															
3	125	C	5	0.536		0.536	0.071		0.046	0.00	0.05	11.6	0.405	26.244	1.62	42.02	35.78	22.20
3	125	E	5															
3	125	W	5															

Appendix 5. ERV & Mineral soil data.

Location Information				C Horizon										C Horizon	Tree Ages					Tree Ages
					(meq/100g)	(g 100g^{-1})	Moisture Content (g 100cm^{-3} or on 100^{-1}) C horizon 7 to 13 October 1996	Estimated Field Capacity C Horizon		Estimated Permanent Wilting Point C Horizon		C horizon Estimated Avail. Water Capacity		Deciduous Age (a)			Coniferous Age (a)		
Toposequence Site	Transect Position	Plot	Slope Position	pHw C	CEC	MC% C Horizon 7 to 13 October 1996	Soil Water 7 to 13 October 1996	(g 100g^{-1})	(g 100cm^{-3})	(g 100g^{-1})	(g 100cm^{-3})	(g 100g^{-1})	(g 100cm^{-3})	Mean	Stdev.	Maximum	Mean	Stdev.	Maximum
Topo	trans	plot	sp_pos	c_phw	c_cec	c_mc713	csw713	c_fc	c_fc_h	c_pwp	c_pwp_h	c_awc	c_awc_h	d_m_a		d_max_a	c_m_a		c_max_a
1	35	C	1	7.82	28.00	17.27	1001.66	36.66	2137.91	14.21	824.15	22.65	1313.75	78	3	81	81	0	81
1	35	E	1											83	7	90	0	0	0
1	35	W	1											88	13	104	77	0	77
1	80	C	2	5.97	21.76	13.44	457.09	29.38	995.88	11.60	394.42	17.68	601.46						
1	80	E	2																
1	80	W	2																
1	100	C	3	6.14	18.69	22.1	1150.97	26.30	1369.95	12.10	630.17	14.20	739.77						
1	100	E	3																
1	100	W	3																
1	120	C	3	5.05	20.48	9.6	657.51	28.67	1976.46	8.51	582.92	20.35	1393.54						
1	120	E	3																
1	120	W	3																
1	150	C	4	7.25	20.59	14.59	673.62	29.47	1360.68	13.05	602.50	16.42	758.17	66	17	103	76	7	84
1	150	E	4											69	3	82	71	11	88
1	150	W	4											94	13	103	71	16	87
1	180	C	4	6.58	11.61	24.33	1226.23	28.23	1422.68	14.68	739.96	13.55	682.91	76	9	82	79	6	88
1	180	E	4											82	10	95	76	8	88
1	180	W	4											82	0	82	74	7	87
1	200	C	5	7.64	15.75	21.43	610.76	27.46	782.62	13.56	386.32	13.91	396.30						
1	200	E	5																
1	200	W	5																
2	12.5	C	1	5.20	20.40	11.38		24.52	0.00	11.12	0.00	13.40	0.00	82	17	95	80	11	72
2	12.5	E	1											69	7	75	81	10	70
2	12.5	W	1											84	22	92	80	5	65
2	50	C	2	5.52	20.81	23.34		29.30	0.00	14.15	0.00	15.15	0.00						
2	50	E	2																
2	50	W	2																
2	65	C	3	6.94	21.04	15.98	502.41	31.03	975.57	14.12	443.99	16.91	531.58	59	28	87	83	6	78
2	65	E	3											78	11	93	81	14	78
2	65	W	3											59	18	87	85	5	72
2	85	C	5	6.04	14.65	21.68	2687.74	23.15	2844.21	18.39	2258.82	4.77	585.39						
2	85	E	5																
2	85	W	5																
3	10	C	1	6.88	18.08	11.59	574.75	25.42	1260.37	11.61	575.89	13.80	684.38	37	11	55	38	6	46
3	10	E	1											47	12	61	38	4	43
3	10	W	1											0	0	0	35	6	40
3	25	C	2	6.65	20.41	15.02	1140.32	28.14	2212.24	12.67	982.22	16.47	1250.03						
3	25	E	2																
3	25	W	2																
3	75	C	3	7.65	19.47	14.91	597.59	28.49	1141.76	10.05	402.68	16.44	738.92	56	3	60	43	0	43
3	75	E	3											67	24	80	43	5	50
3	75	W	3											58	12	67	38	6	48
3	125	C	5	7.76	21.90	25.29	163.68	30.86	200.76	12.40	80.35	18.58	120.41	0	0	0	43	6	50
3	125	E	5											0	0	0	63	22	94
3	125	W	5											0	0	0	40	5	50

Appendix 5. ERV & Mineral soil data.

Location Information				Tree Ages		Tree Ages	Tallest Trees								Tallest Trees							
				Age (s) Deciduous and Coniferous Species Combined			Tallest Conifer (Abies sp.) for each plot								Tallest Deciduous (Populus sp.) for each plot							
Toposequence Site	Transect Position	Plot	Slope Position	Mean	Stdev	Maximum	dbh (cm)	Height (m)	Sapwood Radius (cm)	Age (years)	BAF (m²/ha)	Sapwood Area (cm²)	Sapwood Area (m²/ha) bh	Species	dbh (cm)	Height (m)	Sapwood Radius (cm)	Age (years)	BAF (m²/ha)	Sapwood Area (cm²)	Sapwood Area (m²/ha) bh	Species
topo	trans	plot	slp_pos	dc_m_a		dc_ma_a	c dbhob	c ht	c sapr	c age	c baf	c sapa c	c sapa h		d dbhob	d ht	d sapr	d age	d baf	d sapa c	d sapa h	
1	35	C	1	80	3	81	41.6	19.80	2.2	81	4	220.5	0.65	Abies glauca	46.4	26.18	8.8	81	4	786.2	1.88	Populus tremuloides
1	35	E	1	41	7	90	0	0	0	0	0	0	0	NA	43.7	28.25	13.7	75	4	1168.6	3.19	Populus tremuloides
1	35	W	1	81	12	104	34.3	18.50	3.6	77	4	260.2	1.26	Abies glauca	47.6	31.23	8.0	104	4	668.5	1.50	Populus tremuloides
1	80	C	2																			
1	80	E	2																			
1	80	W	2																			
1	100	C	3																			
1	100	E	3																			
1	100	W	3																			
1	120	C	3																			
1	120	E	3																			
1	120	W	3																			
1	150	C	4	81	13	103	30.1	26.88	5.3	84	4	375.6	2.11	Abies glauca	37.9	31.82	7.0	103	4	541.2	1.82	Populus tremuloides
1	150	E	4	60	13	92	48.1	32.86	3.0	72	4	340.6	0.85	Abies glauca	48.3	27.08	18.1	92	4	1468.2	3.84	Populus tremuloides
1	150	W	4	82	17	103	38.4	30.00	1.6	67	4	130.5	0.48	Abies glauca	47.6	27.90	5.0	84	4	938.5	1.14	Populus tremuloides
1	160	C	4	77	8	88	24.5	25.38	3.3	80	4	189.5	1.61	Abies glauca	29.6	23.22	3.8	88	4	268.3	1.48	Populus tremuloides
1	160	E	4	79	9	93	41.5	30.24	2.8	76	4	276.0	0.82	Abies glauca	31.6	28.84	5.6	80	4	389.5	1.69	Populus tremuloides
1	160	W	4	78	7	87	26.6	27.61	2.9	72	4	175.1	1.38	Abies glauca	38.4	26.00	8.8		4	601.4	2.07	Populus tremuloides
1	200	C	5																			
1	200	E	5																			
1	200	W	5																			
2	12.5	C	1	61	10	93	27.4	16.33	2.2	72	2	174.2	0.59	Abies glauca	34.7	28.20	13.1	75	2	888.9	1.98	Populus tremuloides
2	12.5	E	1	62	9	75	30.0	22.20	6.2	66	2	961.6	1.59	Abies glauca	37.2	29.40	12.4	64	2	888.1	1.76	Populus tremuloides
2	12.5	W	1	62	14	92	30.6	25.44	4.0	53	2	354.3	0.91	Abies glauca	36.8	24.78	10.0	92	2	610.5	1.61	Populus tremuloides
2	50	C	2																			
2	50	E	2																			
2	50	W	2																			
2	65	C	3	61	14	87	36.6	26.75	3.2	76	3	325.7	0.98	Abies glauca	38.4	28.65	9.8	87	3	788.2	2.40	Populus tremuloides
2	65	E	3	70	15	99	36.6	26.75	3.2	76	3	325.7	0.98	Abies glauca	42.9	30.72	12.0	93	3	1194.9	2.42	Populus tremuloides
2	65	W	3	62	13	87	23.9	23.10	2.1	67	3	149.6	0.98	Abies glauca	38.4	28.64	9.8	87	3	788.2	2.40	Populus tremuloides
2	85	C	5																			
2	85	E	5																			
2	85	W	5																			
3	10	C	1	37	8	55	21.1	14.40	4.0	46	2	188.0	1.08	Abies mariana	18.2	14.42	2.6	55	2	91.2	0.60	Populus tremuloides
3	10	E	1	42	10	61	27.0	15.38	7.0	43	2	380.1	1.38	Abies mariana	20.4	18.70	6.5	61	2	262.6	1.56	Populus tremuloides
3	10	W	1	17	8	40	27.7	16.40	5.0	35	2	305.5	1.01	Abies glauca	0	0	0	0	0	0	0	NA
3	25	C	2																			
3	25	E	2																			
3	25	W	2																			
3	75	C	3	50	6	60	12.3	11.38	1.2	43	4	26.9	0.91	Abies glauca	27.7	24.88	1.0	58	4	49.9	0.33	Populus tremuloides
3	75	E	3	55	22	80	15.2	14.24	2.8	41	4	80.5	1.00	Abies glauca	46.3	24.00	5.6		4	601.7	1.43	Populus tremuloides
3	75	W	3	49	14	67	14.2	14.84	2.0	37	4	50.3	1.30	Abies mariana	28.7	24.64	13.2	67	4	968.5	3.70	Populus tremuloides
3	125	C	5	21	0	30	21.8	16.74	0.8	30	4	12.6	0.14	Abies glauca	0	0	0	0	0	0	0	NA
3	125	E	5	32	22	84	36.9	16.92	2.5	77	4	130.8	0.61	Abies mariana	0	0	0	0	0	0	0	NA
3	125	W	5	20	5	30	17.9	13.20	2.0	30	4	75.9	1.28	Abies mariana	0	0	0	0	0	0	0	NA

APPENDIX III

Two-way ANOVA Interactions

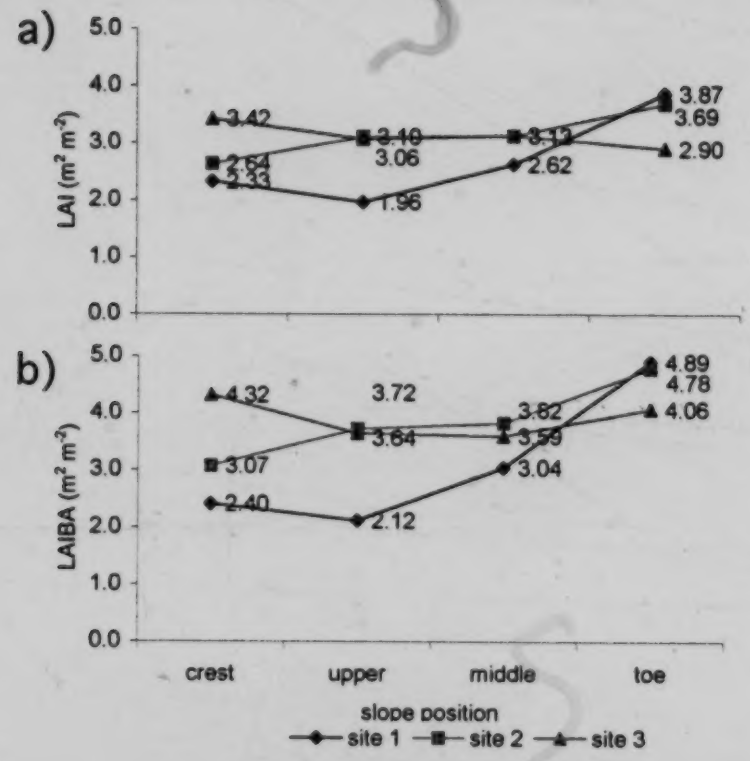

Figure Appendix III-1. The significant ($p \leq 0.05$) interaction for the two-way ANOVA comparison of toposequence sites and slope positions (eq. 3-5) by a) LAI (Table 3-3), and b) LAI adj. BA.

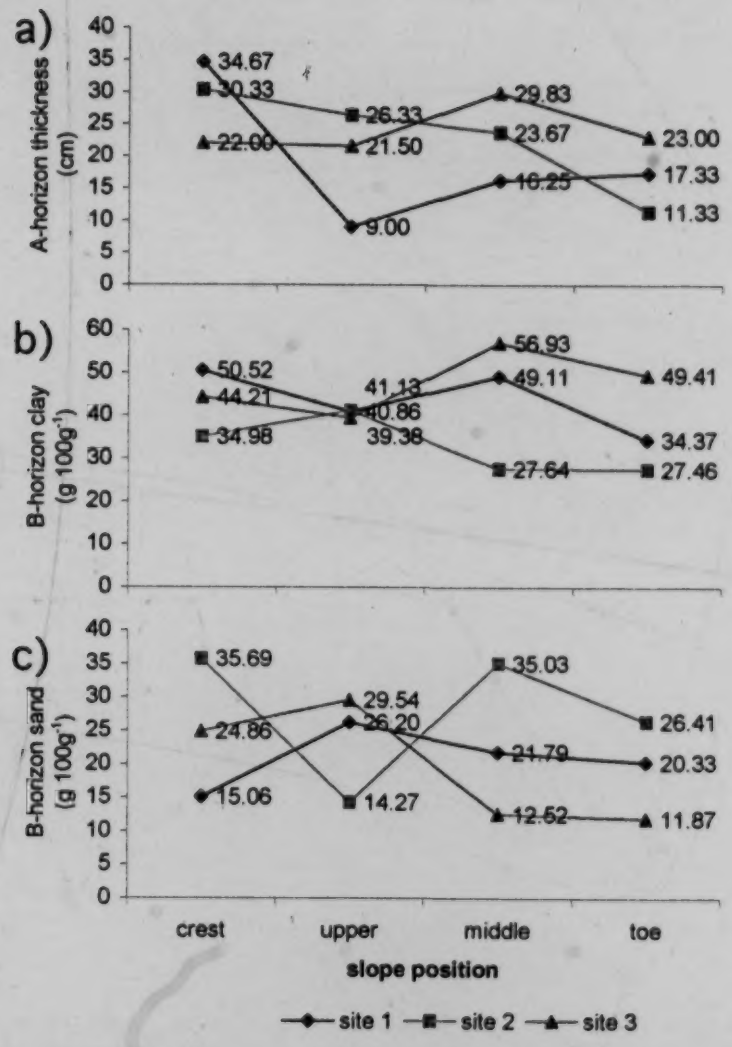

Figure Appendix III-2. The significant ($p \leq 0.05$) interaction for the two-way ANOVA comparison of toposequence sites and slope positions (eq. 3-5) by a) A-horizon thickness, b) B-horizon clay content, and c) B-horizon sand content (Table 3-4).

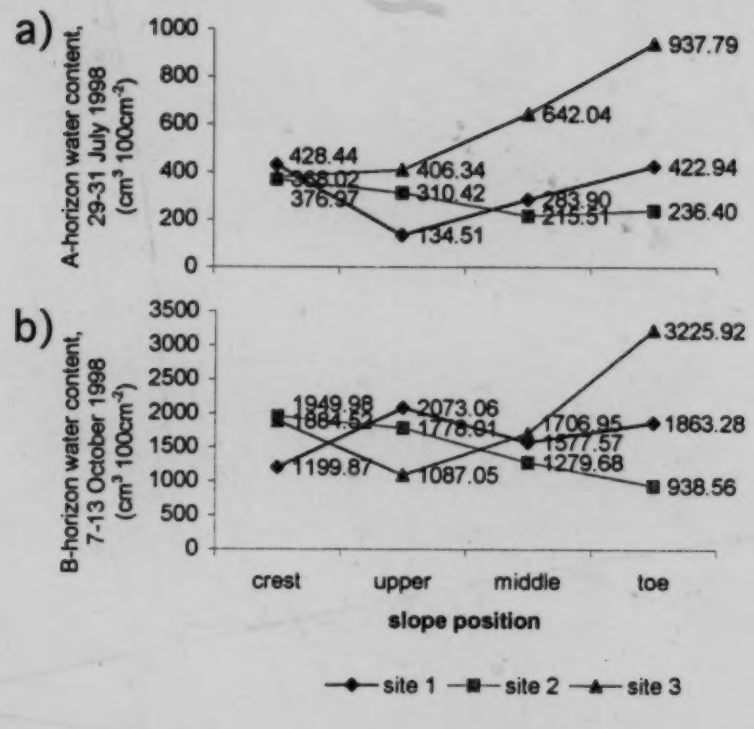

Figure Appendix III-3. The significant ($p \leq 0.05$) interaction for the two-way ANOVA comparison of toposequence sites and slope positions (eq. 3-5) by a) A-horizon (29 to 31 July) and b) B-horizon (7 to 13 August) water contents (Table 3-4).

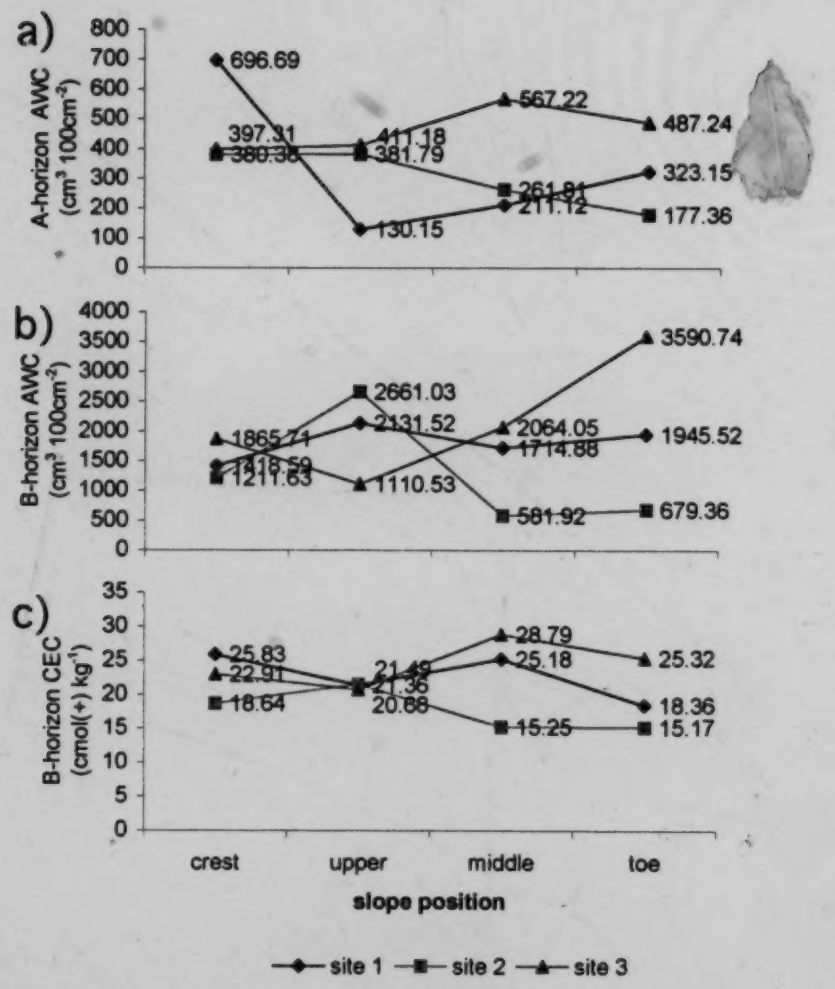

Figure Appendix III-4. The significant ($p \leq 0.05$) interaction for the two-way ANOVA comparison of toposequence sites and slope positions (eq. 3-5) by a) A-horizon and b) B-horizon available water capacity, and c) B-horizon cation exchange capacity (Table 3-4).

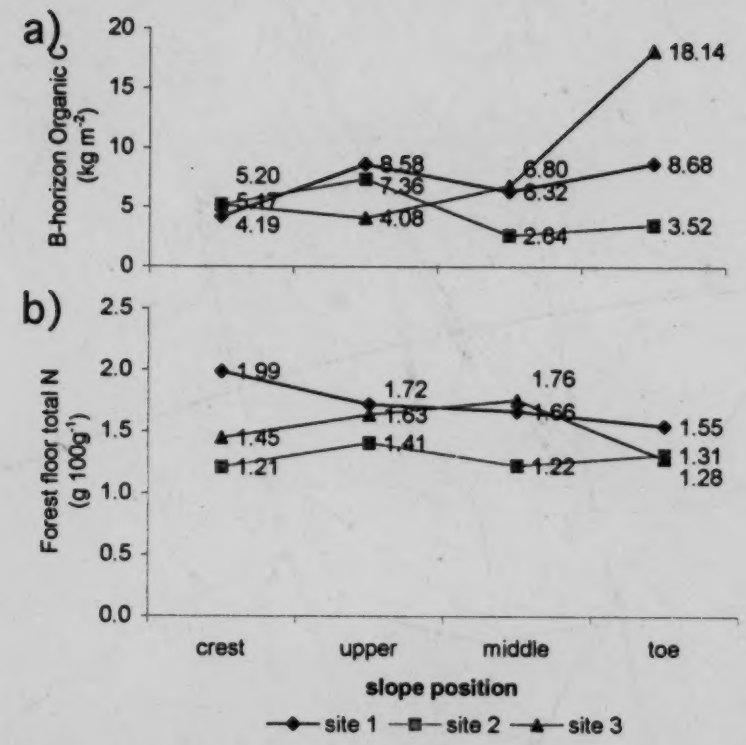

Figure Appendix III-5. The significant ($p \leq 0.05$) interaction for the two-way ANOVA comparison of toposequence sites and slope positions (eq. 4-1) by a) B-horizon organic C (by volume) and b) forest floor total N (by mass; Table 4-1).

APPENDIX IV

Point Sample Plot Mensuration Data.

Tree Volume Calculations

Individual tree volumes were calculated using general taper models, or species specific models when appropriate, for major tree species in the Lower Foothills natural sub-region of west central Alberta (Huang, 1994). Lower Foothills natural sub-region taper models were found for general softwood groups, general hardwood groups, black spruce (*Picea mariana* (Mill) BSP), balsam fir (*Abies balsamea* (L.) Mill.), aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), white spruce (*Picea glauca* (Moench) Voss), lodgepole pine (*Pinus contorta* Doul. ex. Loud var. *latifolia* Engelm.), jack pine (*Pinus banksiana* Lamb.), rocky mountain douglas-fir (*Psuedotsuga menziesii* var. *glauca* (Bessn.) Franco), engelmann spruce (*Picea engelmannii* Parry ex. Engelm.). The general softwood group taper model was used for tamarack (*Larix laricina* (Du Roi) K. Koch), and the general hardwood group taper model was used for white birch (*Betula papyrifera* Marsh.) and *Salix* spp.

Taper models and independent variables, diameter outside bark at 1.3 m (D) and tree height (H), were used to calculate diameter inside bark (d) at any height (h). The volume of section between two estimated diameters was calculated according to Huber's Formula (Husch *et al.*, 1982). The volume of the tip of the trees was calculated using the formula for a cone. Paraboloid and tip volumes were summed for the total individual tree volume. Tree volume on a per hectare basis was calculated from the sum of the individual tree volume per plot and the stand table factor for each tree in the plot.

Literature Cited

Huang, S. 1994. Ecologically based Individual tree volume equations for major Alberta tree species. Report #3 summary of equations and estimation coefficients of ecologically based individual tree volume estimation in Alberta. Edmonton, Alberta Environmental Protection, Land and Forest Services, Forest Management Division. Rept No. 3 T/292. 23 pp.

Husch, B., C. I. Miller, and T. W. Beers. 1982. Forest mensuration. John Wiley & Sons, New York. 402 pp.

Sapwood Area Calculation

Sapwood area was measured for spruce and aspen. Sapwood area per tree (eq. 1) and sapwood area per hectare (eq. 2) were calculated from sampled diameters and sapwood radius at 1.3 m.

$$[1] \quad Tree\ Sapwood\ Area\ (m^2) = \left[\pi\left(\frac{dbh}{2}\frac{cm}{1}\right)^2 \times \frac{1^2}{100^2}\frac{m^2}{cm^2}\right] - \left[\pi\left(Sapwood\ Radius\ (cm)\right)^2 \times \frac{1^2}{100^2}\frac{m^2}{cm^2}\right]$$

$$[2] \quad Plot\ Sapwood\ Area\left(\frac{m^2}{ha}\right) = \sum\left(Tree\ Sapwood\ Area\left(\frac{m^2}{tree}\right) \times Stand\ Table\ Factor\left(\frac{trees}{ha}\right)\right)$$

Appendix IV. PSP Data

Toposequence	Transect Position	Plot	Species	dhbob (cm)	Height (m)	Sapwood Radius (cm)	Bark Thickness (cm)	Age (years)	BAF	Total BA (cm^2) bhob	Bark Area (cm^2) bh	Sapwood Area (cm^2)	Shongming's Taper Individual Tree Volumes (m^3)	Honer's Equation Individual Tree Volumes (m^3)	Original Order	Stand Table Factor (STF) (number of tree/ha represented by sampled tree)	using STF Sapwood Area (m^2/ha)	using STF Tree Volume (Shongming's Taper Model) (m^3/ha)
1	35	C	*Populus tremuloides*	40.9	25.74	16.2	0.8	78	4	1313.8	100.8	1156.29	1.3643	1.4943	104	30.46	3.52	41.54
1	35	C	*Populus tremuloides*	38.8	24.2	13.8	1.1	81	4	1182.4	130.3	953.57	1.1582	1.2595	105	33.63	3.23	39.16
1	35	C	*Picea glauca*	41.6	19.8	2.2	0.4	81	4	1359.2	51.8	220.54	1.0612	1.1151	106	29.43	0.65	31.23
1	35	C	*Populus tremuloides*	34.5	24	6.7	0.7	75	4	934.8	74.3	510.82	0.9182	0.9671	107	42.79	2.19	39.29
1	35	C	*Populus tremuloides*	29.2	25	5.8	0.8	76	4	669.7	71.4	355.00	0.6976	0.7384	108	59.73	2.12	41.67
1	35	C	*Populus tremuloides*	46.4	26.18	6.8	0.4	81	4	1690.9	57.6	788.16	1.7627	1.9563	109	23.66	1.86	41.70
1	35	C	*Populus balsamifera*	25.2	22.4	1.9	0.4		4	498.8	31.2	107.91	0.4015	0.4896	110	80.20	0.87	32.20
1	35	E	*Populus tremuloides*	38.1	22.32	7.4	1.2		4	1140.1	139.1	574.60	1.0295	1.1149	111	35.08	2.02	36.12
1	35	E	*Populus tremuloides*	39.3	26.68	6.4	0.6	81	4	1213.0	72.9	588.55	1.3125	1.4335	112	32.98	1.94	43.28
1	35	E	*Populus tremuloides*	33.8	27	6.6	0.7	86	4	897.3	72.8	491.19	0.9971	1.0739	113	44.56	2.19	44.45
1	35	E	*Populus tremuloides*	28.8	25.44	6	0.7	69	4	651.4	61.8	367.97	0.6926	0.7318	114	61.40	2.26	42.53
1	35	E	*Populus tremuloides*	21.2	24.2	4.4	0.7	84	4	353.0	45.1	187.14	0.3673	0.3760	115	113.32	2.12	41.62
1	35	E	*Populus tremuloides*	42.1	28.25	12.8	0.8		4	1392.0	103.8	1074.42	1.5960	1.7487	116	28.73	3.09	45.57
1	35	E	*Populus tremuloides*	43.7	28.25	13.7	0.7	75	4	1499.9	94.6	1196.63	1.7022	1.8841	117	26.67	3.19	45.40
1	35	E	*Populus tremuloides*	45.6	25.07	6.8	0.5	88	4	1633.1	70.8	758.03	1.6308	1.8061	118	24.49	1.86	39.94
1	35	E	*Populus tremuloides*	19.4	12.74	3.8	0.3	87	4	295.6	18.0	168.23	0.1616	0.1612	119	135.32	2.28	21.86
1	35	E	*Populus tremuloides*	39.5	27.6	2.8	0.3	90	4	1225.4	36.9	285.88	1.3722	1.5015	120	32.64	0.93	44.79
1	35	W	*Populus tremuloides*	28.5	26.83	6.6	0.7	90	4	637.9	61.1	392.95	0.7718	0.8190	89	62.70	2.46	48.40
1	35	W	*Populus tremuloides*	32.2	26.13	2.4	1	64	4	814.3	98.0	126.67	0.8800	0.9412	90	49.12	0.62	43.22
1	35	W	*Populus tremuloides*	36.2	28.53	4.9	0.3	96	4	973.1	32.9	433.54	1.1408	1.2354	91	41.10	1.78	46.89
1	35	W	*Populus tremuloides*	45	26.13	12.5	1.5		4	1590.4	205.0	1071.28	1.6600	1.8381	92	25.15	2.69	41.75
1	35	W	*Populus tremuloides*	45	25.53	3.2	0.8		4	1590.4	111.1	309.13	1.6208	1.7933	93	25.15	0.78	40.76
1	35	W	*Populus tremuloides*	26.5	27.93	3.7	0.6		4	551.5	48.8	216.20	0.6506	0.6844	94	72.52	1.57	47.18
1	35	W	*Populus tremuloides*	32.9	29.43	9	0.8	93	4	850.1	80.7	595.08	1.0357	1.1158	95	47.05	2.80	48.73
1	35	W	*Populus tremuloides*	25.6	21.63	4	0.6	81	4	514.7	47.1	224.31	0.4690	0.4870	96	77.71	1.74	36.45
1	35	W	*Picea glauca*	34.3	19.53	3.8	0.7	77	4	924.0	73.9	290.22	0.7323	0.7499	97	43.29	1.26	31.70
1	35	W	*Populus tremuloides*	26.2	27.64	1.4	0.8	68	4	539.1	63.6	45.24	0.6298	0.6816	98	74.19	0.34	46.72
1	35	W	*Populus tremuloides*	30.8	25.83	4.8	0.5		4	745.1	47.6	344.48	0.7995	0.8906	99	53.69	1.85	42.92
1	35	W	*Populus tremuloides*	37.2	27.03	4	0.6		4	1086.9	69.0	348.21	1.1984	1.3023	100	36.80	1.28	44.11
1	35	W	*Populus tremuloides*	47.6	31.23	6	0.8	104	4	1779.5	117.6	668.52	2.2201	2.4898	101	22.48	1.50	49.90
1	35	W	*Populus tremuloides*	27.4	22.88	6.9	0.6	86	4	589.6	50.5	393.86	0.5654	0.5919	102	67.84	2.67	38.36
1	35	W	*Populus tremuloides*	28.5	26.4	1	0.8	56	4	637.9	69.6	16.78	0.7062	0.7454	103	62.70	0.11	44.22
1	150	C	*Picea glauca*	19.7	21.17	2.8	0.4	67	4	304.8	24.3	124.41	0.2819	0.2635	68	131.23	1.63	36.99
1	150	C	*Picea glauca*	25.7	17.08	2.2	0.5	76	4	518.7	39.6	122.84	0.3725	0.3783	69	77.11	0.95	28.72
1	150	C	*Populus tremuloides*	36.3	24.65	4.6	0.5	81	4	1034.9	56.2	401.87	1.0407	1.1242	70	38.65	1.55	40.22
1	150	C	*Picea glauca*	24.8	23.78	2.6	0.4	81	4	483.1	30.7	150.67	0.4907	0.4563	71	82.81	1.25	40.63
1	150	C	*Populus tremuloides*	20.8	21.78	2.6	0.4		4	339.8	25.6	123.02	0.3183	0.3238	72	117.72	1.45	37.47
1	150	C	*Picea glauca*	20.3	20.25	3.1	0.4	80	4	323.7	25.0	142.50	0.2850	0.2702	73	123.59	1.76	35.22
1	150	C	*Picea glauca*	23.4	21.6	3.4	0.4	67	4	430.1	28.9	184.73	0.3983	0.3775	74	93.01	1.72	37.04
1	150	C	*Populus tremuloides*	28.3	24.3	4.8	0.9	90	4	674.3	80.3	289.15	0.6828	0.7214	75	59.32	1.72	40.50
1	150	C	*Populus tremuloides*	33.2	25.38	5.4	0.6	91	4	865.7	61.4	410.17	0.9062	0.9700	76	46.21	1.90	41.82
1	150	C	*Picea glauca*	30.1	26.88	5.3	0.4	84	4	711.6	37.3	375.61	0.8001	0.7360	77	58.21	2.11	44.98
1	150	C	*Populus tremuloides*	21.2	21.75	2.4	0.6	56	4	353.0	38.8	102.92	0.3296	0.3359	78	113.32	1.17	37.34
1	150	C	*Populus tremuloides*	37.9	31.92	7	1.2	103	4	1128.2	138.4	541.17	1.4735	1.6162	79	35.46	1.92	52.25
1	150	C	*Populus tremuloides*	32.9	27.84	10.5	0.8	97	4	850.1	80.7	658.23	0.9786	1.0513	80	47.06	3.10	46.04
1	150	E	*Picea glauca*	27.3	18.57	2.2	0.4	59	4	585.3	33.8	139.68	0.4547	0.4565	81	68.34	0.95	31.07
1	150	E	*Picea glauca*	42.7	30.63	2.2	0.6	60	4	1432.0	79.4	200.56	1.7464	1.6264	82	27.93	0.56	48.78
1	150	E	*Picea glauca*	53.9	29.73	4.8	0.5	77	4	2281.7	83.9	656.53	2.5838	2.5376	83	17.53	1.15	45.29
1	150	E	*Picea glauca*	45.1	32.86	3	0.4	72	4	1597.5	56.2	340.61	2.0764	1.9053	84	25.04	0.85	51.99
1	150	E	*Picea glauca*	33.3	28.22	2.8	0.4	86	4	870.9	41.3	226.95	1.0148	0.9332	85	46.93	1.04	48.61

Appendix IV. PSP Data

Toposequence	Transect Position	Plot	Species	dhbob (cm)	Height (m)	Sapwood Radius (cm)	Bark Thickness (cm)	Age (years)	BAF	Total BA (cm^2) bhob	Bark Area (cm^2) bh	Sapwood Area (cm^2)	Shongming's Taper: Individual Tree Volumes (m^3)	Honer's Equation: Individual Tree Volumes (m^3)	Original Order	Stand Table Factor (STF) (number of trees/ha represented by sampled tree)	using STF: Sapwood Area (m^2/ha)	using STF: Tree Volume (Shongming's Taper Model) (m^3/ha)
1	150	E	*Populus tremuloides*	46.3	27.06	16.1	0.8	92	4	1683.7	114.4	1489.18	1.8165	2.0198	86	23.76	3.54	43.16
1	150	E	*Populus tremuloides*	40.1	24.33	8.2	0.7	90	4	1262.9	86.6	735.13	1.2397	1.3530	87	31.67	2.33	39.26
1	150	E	*Populus tremuloides*	32	25.61	7.6	0.7	86	4	804.2	68.8	513.74	0.8520	0.9098	88	49.74	2.56	42.38
1	150	W	*Picea glauca*	25.9	25.8	3.4	0.4	74	4	526.9	32.0	208.29	0.5791	0.6288	59	75.92	1.58	43.97
1	150	W	*Picea glauca*	30.7	26.04	4.7	0.5	79	4	740.2	47.4	336.46	0.8027	0.7481	60	54.04	1.82	43.38
1	150	W	*Populus tremuloides*	47.6	27.9	5	1.1	84	4	1779.5	160.7	508.47	1.9763	2.2058	61	22.48	1.14	44.42
1	150	W	*Picea glauca*	30.7	22.96	2.2	0.8	82	4	740.2	75.1	121.83	0.7050	0.6909	62	54.04	0.66	38.09
1	150	W	*Picea glauca*	8.9	9.3	0.5	0.3	50	4	62.2	8.1	5.09	0.0267	0.0271	63	642.97	0.33	17.17
1	150	W	*Populus tremuloides*	45.1	26.1	11.7	1.1	103	4	1597.5	152.1	1075.62	1.6851	1.8441	64	25.04	2.69	41.69
1	150	W	*Picea glauca*	39.4	30	1.8	0.6	87	4	1219.2	73.1	139.49	1.4734	1.3646	65	32.81	0.46	48.34
1	150	W	*Picea glauca*	23.1	20.4	2.4	0.5	71	4	419.1	35.5	120.57	0.3663	0.3520	66	95.44	1.15	34.96
1	150	W	*Picea glauca*	7.2	6	0.6	0.3	48	4	40.7	6.5	5.94	0.0108	0.0119	67	982.44	0.58	10.62
1	180	C	*Picea glauca*	25.6	24.03	2.4	0.8	72	4	514.7	62.3	112.59	0.5262	0.4900	32	77.71	0.88	40.89
1	180	C	*Picea glauca*	28.2	24.06	1.6	0.6	88	4	624.6	52.0	81.68	0.6318	0.5965	33	64.04	0.52	40.46
1	180	C	*Picea glauca*	22.5	22.12	2.8	0.4	72	4	397.6	27.8	145.52	0.3790	0.3555	34	100.60	1.46	38.13
1	180	C	*Picea glauca*	29.6	19.14	5.1	0.5	82	4	688.1	45.7	346.83	0.5453	0.5497	35	58.13	2.02	31.70
1	180	C	*Picea glauca*	17.4	19.44	1.4	0.3	74	4	237.8	16.1	54.26	0.2041	0.1923	36	168.22	0.91	34.34
1	180	C	*Picea glauca*	27	20.52	1.8	0.5	86	4	572.6	41.6	100.88	0.4938	0.4830	37	69.86	0.70	34.50
1	180	C	*Populus tremuloides*	29.8	23.22	3.8	0.6	69	4	697.5	55.0	255.35	0.6729	0.7112	38	57.35	1.46	38.59
1	180	C	*Picea glauca*	29.4	22.14	2.8	0.6	75	4	678.9	54.3	179.70	0.6259	0.6074	39	58.92	1.06	36.88
1	180	C	*Picea glauca*	16.7	18.46	1.6	0.4	68	4	219.0	20.5	55.42	0.1790	0.1700	40	182.62	1.01	32.69
1	180	C	*Picea glauca*	24.4	21.06	2.2	0.6	82	4	467.6	44.9	108.57	0.4195	0.4025	41	85.54	0.93	35.89
1	180	C	*Picea glauca*	10.9	14.03	0.6	0.3	71	4	93.3	10.0	9.42	0.0598	0.0579	42	428.66	0.40	25.64
1	180	C	*Picea glauca*	24.5	25.38	3.3	0.4	80	4	471.4	30.3	189.50	0.5128	0.4675	43	84.85	1.61	43.51
1	180	C	*Picea glauca*	35.7	22.41	3.1	0.3	81	4	1001.0	33.4	284.13	0.9086	0.9039	44	39.96	1.14	36.31
1	180	C	*Populus tremuloides*	24.7	23.22	2.8	0.7	82	4	479.2	52.8	139.86	0.4710	0.4886	45	83.48	1.17	39.32
1	180	C	*Picea glauca*	18.5	17.75	1.3	0.4	84	4	268.8	22.7	47.50	0.2089	0.2022	46	148.81	0.71	31.09
1	180	E	*Picea glauca*	27.5	25.46	2.2	0.4	73	4	594.0	34.1	140.81	0.6394	0.5907	18	67.34	0.95	43.06
1	180	E	*Picea glauca*	36.8	25.76	2.9	0.4	78	4	1063.6	45.7	263.11	1.1104	1.0884	19	37.61	0.99	41.76
1	180	E	*Populus tremuloides*	39.2	22.68	5.2	0.4	83	4	1206.9	48.8	506.68	1.1048	1.2003	20	33.14	1.68	36.62
1	180	E	*Populus tremuloides*	39.7	23.24	3.1	1.1	89	4	1237.9	133.4	223.05	1.1602	1.2633	21	32.31	0.72	37.49
1	180	E	*Picea glauca*	20.9	19.76	2.6	0.6	70	4	343.1	38.3	111.21	0.2938	0.2810	22	116.59	1.30	34.25
1	180	E	*Populus tremuloides*	34.2	28.28	6	0.7	83	4	918.6	73.7	457.89	1.0702	1.1863	23	43.54	1.99	46.60
1	180	E	*Populus tremuloides*	31.6	28.84	5.6	0.7	80	4	784.3	68.0	389.46	0.9398	1.0072	24	51.00	1.99	47.93
1	180	E	*Populus tremuloides*	27.8	24.64	6.8	0.6	67	4	607.0	51.3	397.35	0.6268	0.6591	25	65.90	2.62	41.31
1	180	E	*Picea glauca*	37.8	27.16	2.9	0.3	88	4	1122.2	35.3	282.62	1.2322	1.1606	26	35.64	1.01	43.92
1	180	E	*Picea glauca*	40.8	28	3.7	0.4	86	4	1307.4	50.8	380.48	1.4620	1.3930	27	30.59	1.16	44.73
1	180	E	*Picea glauca*	36.2	24.64	1.8	0.5	79	4	1029.2	56.1	138.45	1.0287	0.9984	28	38.86	0.54	39.98
1	180	E	*Picea glauca*	16.1	14.04	1.1	0.2	63	4	203.6	10.0	41.85	0.1260	0.1263	29	196.46	0.82	24.76
1	180	E	*Picea glauca*	20.7	22.14	2.8	0.4	70	4	336.5	25.5	122.33	0.3242	0.3011	30	118.86	1.45	38.53
1	180	E	*Picea glauca*	41.5	30.24	2.8	0.5	78	4	1352.7	64.4	276.02	1.6355	1.9225	31	29.67	0.82	48.38
1	180	W	*Picea glauca*	25.6	27.81	2.9	0.4	72	4	514.7	31.7	175.14	0.6124	0.5457	47	77.71	1.36	47.59
1	180	W	*Picea glauca*	29.3	27	2.4	0.4	78	4	674.3	36.3	166.50	0.7631	0.6997	48	59.32	0.99	45.27
1	180	W	*Picea glauca*	16.1	15.96	0.7	0.3	68	4	203.6	14.9	18.98	0.1411	0.1383	49	196.46	0.37	27.73
1	180	W	*Picea glauca*	26.2	24.57	1.8	0.5	80	4	539.1	40.4	97.61	0.5624	0.5219	50	74.19	0.72	41.73
1	180	W	*Populus tremuloides*	29.9	23.22	4.4	0.4	82	4	702.2	37.1	315.42	0.6772	0.7159	51	56.97	1.80	38.58
1	180	W	*Picea glauca*	36.4	26.88	3.6	0.6	87	4	1040.6	67.5	303.48	1.1376	1.0764	52	38.44	1.17	43.73
1	180	W	*Picea glauca*	29.1	24.92	3.8	0.5	73	4	665.1	44.9	257.11	0.6946	0.6506	53	60.14	1.55	41.76
1	180	W	*Populus tremuloides*	39.4	28	6.9	0.6		4	1219.2	73.1	631.37	1.3650	1.5170	54	32.81	2.07	49.44
1	180	W	*Picea glauca*	24.7	22.41	2.5	0.5	73	4	479.2	38.0	136.35	0.4578	0.4327	55	83.48	1.14	38.22

Appendix IV. PSP Data

Toposequence	Transect Position	Plot	Species	dhbob (cm)	Height (m)	Sapwood Radius (cm)	Bark Thickness (cm)	Age (years)	BAF	Total BA (cm^2) bhob	Bark Area (cm^2) bh	Sapwood Area (cm^2)	Shongming's Taper Individual Tree Volumes (m^3)	Honer's Equation Individual Tree Volumes (m^3)	Original Order	Stand Table Factor (STF) (number of trees/ha represented by sampled tree)	using STF Sapwood Area (m^2/ha)	using STF Tree Volume (Shongming's Taper Model) (m^3/ha)
1	180	W	*Picea glauca*	26.8	24	3.8	0.6	72	4	651.4	53.2	245.30	0.6538	0.6196	56	61.40	1.51	40.14
1	180	W	*Picea glauca*	24.3	24.84	1.3	0.5	79	4	463.8	37.4	56.55	0.4941	0.4526	57	86.25	0.49	42.62
1	180	W	*Picea glauca*	15.9	15.39	0.7	0.3	61	4	198.6	14.7	18.72	0.1363	0.1330	58	201.45	0.38	27.25
1	280	C	*Picea glauca*	13.1	8.28	2.2	0.4	32	4	134.8	16.0	59.38	0.0499	0.0528	6	296.78	1.76	14.81
1	280	C	*Salix spp.*	11.2	8.16	1.8	0.2	40	4	98.5	6.9	46.24	0.0354	NA	7	406.01	1.88	14.37
1	280	C	*Picea glauca*	27.2	14.52	5.2	0.6	35	4	581.1	50.1	309.26	0.3511	0.3706	8	68.84	2.13	24.17
1	280	C	*Larix laricina*	53.5	24.6	3.6	0.5	70	4	2248.0	83.3	461.10	2.1195	NA	9	17.79	0.86	37.71
1	280	C	*Salix spp.*	6.4	6.93	0.8	0.4	36	4	32.2	7.5	6.53	0.0105	NA	10	1243.40	0.81	13.01
1	280	C	*Salix spp.*	8.4	8	0.7	0.3	45	4	55.4	7.6	9.30	0.0194	NA	11	721.79	0.67	13.99
1	280	E	*Picea mariana*	15.4	10.44	1.6	0.4	34	4	186.3	18.8	50.52	0.0874	0.0906	12	214.75	1.08	18.77
1	280	E	*Larix laricina*	17.2	15	2.8	0.5	35	4	232.4	26.2	100.44	0.1588	NA	13	172.15	1.73	27.35
1	280	E	*Larix laricina*	21.5	16.2	3	0.4	26	4	363.1	26.5	147.84	0.2629	NA	14	110.18	1.63	28.96
1	280	E	*Picea glauca*	36.4	20.2	6.4	0.6	57	4	1158.1	71.3	572.15	0.9340	0.9651	15	34.54	1.98	32.26
1	280	E	*Picea glauca*	18.6	15.7	4.2	0.5	45	4	271.7	28.4	161.57	0.1860	0.1850	16	147.21	2.38	27.39
1	280	E	*Picea glauca*	28.7	18.9	3.4	0.7	53	4	646.9	61.6	208.66	0.5087	0.5116	17	61.83	1.29	31.45
1	280	W	*Salix spp.*	6.2	5.92	1.2	0.4		4	30.2	7.3	11.56	0.0085	NA	1	1324.91	1.53	11.26
1	280	W	*Salix spp.*	6.2	4.56	0.8	0.3	31	4	30.2	5.6	8.01	0.0065	NA	2	1324.91	1.06	8.65
1	280	W	*Salix spp.*	1.7	1.68	0.5	0.1	9	4	2.3	0.5	1.38	0.0002	NA	3	17622.69	2.44	3.60
1	280	W	*Salix spp.*	2.1	1.98	0.7	0.2	8	4	3.5	1.2	1.88	0.0004	NA	4	11548.66	2.18	4.49
1	280	W	*Salix spp.*	5.8	5.68	1	0.3	17	4	26.4	5.2	9.90	0.0071	NA	5	1513.96	1.50	10.74
2	12.5	C	*Populus tremuloides*	33.5	20.34	10.9		63	2	881.4	0.0	773.90	0.73	NA	328	22.69	1.76	16.64
2	12.5	C	*Populus tremuloides*	27.2	22.73	4.2		66	2	581.1	0.0	303.48	0.5537	0.5793	329	34.42	1.04	19.06
2	12.5	C	*Populus tremuloides*	22.6	24.42	2		68	2	401.1	0.0	129.43	0.4187	0.4314	330	49.86	0.65	20.88
2	12.5	C	*Populus tremuloides*	26.3	23.39	6.8		61	2	543.3	0.0	416.58	0.5347	0.5582	331	36.82	1.53	19.69
2	12.5	C	*Populus tremuloides*	27.4	22.68	8.1		44	2	589.6	0.0	491.13	0.5602	0.5865	332	33.92	1.67	19.00
2	12.5	C	*Populus tremuloides*	20.2	20.79	3.2		60	2	320.5	0.0	170.90	0.2871	0.2908	333	62.41	1.07	17.92
2	12.5	C	*Populus tremuloides*	23.4	19.4	4.4		65	2	430.1	0.0	262.64	0.3537	0.3629	334	46.51	1.22	16.46
2	12.5	C	*Populus tremuloides*	34.7	26.2	13.1		75	2	945.7	0.0	888.95	1.0170	1.0961	335	21.15	1.88	21.51
2	12.5	C	*Populus balsamifera*	16.5	16	4		32	2	213.8	0.0	157.08	0.1257	0.1476	336	93.53	1.47	11.76
2	12.5	C	*Populus tremuloides*	15.8	16.6	3.4		41	2	196.1	0.0	132.45	0.1449	0.1424	337	102.01	1.35	14.78
2	12.5	C	*Populus tremuloides*	39.4	24.38	10.4		54	2	1219.2	0.0	947.50	1.2016	1.3090	338	16.40	1.55	19.71
2	12.5	C	*Populus tremuloides*	38.7	25.92	9.2		60	2	1176.3	0.0	852.63	1.2376	1.3479	339	17.00	1.45	21.04
2	12.5	C	*Picea glauca*	13.6	14.75	3.1		56	2	145.3	0.0	102.26	0.0963	0.0939	340	137.68	1.41	13.26
2	12.5	C	*Picea glauca*	27.4	16.33	2.2		72	2	589.6	0.0	174.17	0.4011	0.4146	341	33.92	0.59	13.61
2	12.5	C	*Populus tremuloides*	21.2	17.67	5.3		42	2	353.0	0.0	264.74	0.2666	0.2702	342	56.66	1.50	15.11
2	12.5	C	*Populus tremuloides*	34.4	22.88	14.6		60	2	929.4	0.0	906.17	0.8707	0.9330	343	21.52	1.95	18.74
2	12.5	C	*Picea glauca*	11.1	11.04	1.8		52	2	96.8	0.0	52.59	0.0485	0.0489	344	206.68	1.09	10.03
2	12.5	C	*Populus tremuloides*	36.3	25.48	16.6		93	2	1034.9	0.0	1027.36	1.0766	1.1645	345	19.33	1.99	20.81
2	12.5	NE	*Picea glauca*	27.6	18.4	11		67	2	598.3	0.0	573.65	0.4596	0.4632	346	33.43	1.92	15.37
2	12.5	NE	*Populus tremuloides*	31.2	26.6	10		65	2	764.5	0.0	666.02	0.8442	0.9006	347	26.16	1.74	22.08
2	12.5	NE	*Populus tremuloides*	34.6	28.2	12		75	2	940.2	0.0	852.00	1.0909	1.1789	348	21.27	1.81	23.20
2	12.5	NE	*Populus tremuloides*	28.5	21.6	8		52	2	637.9	0.0	515.22	0.5742	0.6027	349	31.35	1.62	18.00
2	12.5	NE	*Picea glauca*	7.8	6.5	3.2		40	2	47.8	0.0	46.24	0.0145	0.0150	350	418.55	1.94	6.09
2	12.5	NE	*Picea glauca*	23.7	17	5.2		70	2	441.2	0.0	302.22	0.3173	0.3205	351	45.34	1.37	14.39
2	12.5	NE	*Picea glauca*	25.3	19.11	4.9		64	2	502.7	0.0	314.03	0.4061	0.4011	352	39.78	1.25	16.16
2	12.5	NE	*Picea glauca*	22	17.4	1.4		62	2	380.1	0.0	90.60	0.2836	0.2814	353	52.61	0.48	14.92
2	12.5	NE	*Populus tremuloides*	31.7	23.04	10.2		60	2	789.2	0.0	668.95	0.7506	0.7981	354	25.34	1.75	19.02
2	12.5	NE	*Populus tremuloides*	31.1	23.4	10.4		68	2	759.6	0.0	676.32	0.7356	0.7809	355	26.33	1.78	19.37
2	12.5	NE	*Populus tremuloides*	30.	22.2	10.1		58	2	706.9	0.0	631.43	0.6506	0.6873	356	28.29	1.79	18.41
2	12.5	NE	*Picea glauca*	24.1	14	3.7		58	2	456.2	0.0	237.13	0.2681	0.2824	357	43.84	1.04	11.75

Appendix IV. PSP Data

Toposequence	Transect Position	Plot	Species	dhbob (cm)	Height (m)	Sapwood Radius (cm)	Bark Thickness (cm)	Age (years)	BAF	Total BA (cm^2) bhob	Bark Area (cm^2) bh	Sapwood Area (cm^2)	Shongming's Taper Individual Tree Volumes (m^3)	Honer's Equation Individual Tree Volumes (m^3)	Original Order	Stand Table Factor (STF) (number of trees/ha represented by sampled tree)	using STF Sapwood Area (m^2/ha)	using STF Tree Volume (Shongming's Taper Model) (m^3/ha)
2	12.5	NE	*Picea glauca*	30	22.2	8.2		69	2	706.9	0.0	561.59	0.6518	0.6337	358	28.29	1.59	18.44
2	12.5	NE	*Populus tremuloides*	37.2	29.4	12.4		64	2	1086.9	0.0	966.10	1.3067	1.4250	359	18.40	1.78	24.05
2	12.5	SW	*Populus tremuloides*	35.8	24.78	10		92	2	1006.6	0.0	810.53	1.0192	1.0996	313	19.87	1.61	20.25
2	12.5	SW	*Picea glauca*	21.8	18.48	3.6		64	2	368.4	0.0	203.58	0.2916	0.2847	314	54.58	1.11	15.91
2	12.5	SW	*Picea glauca*	15	16.6	3.2		63	2	176.7	0.0	118.63	0.1309	0.1259	315	113.18	1.34	14.82
2	12.5	SW	*Picea glauca*	14.3	12.8	6.6		65	2	160.6	0.0	159.66	0.0918	0.0922	316	124.53	1.99	11.43
2	12.5	SW	*Picea glauca*	25.7	19.44	3.2		63	2	518.7	0.0	226.19	0.4257	0.4195	317	38.55	0.87	16.41
2	12.5	SW	*Populus tremuloides*	28	23	8.2		62	2	615.8	0.0	510.07	0.5913	0.6216	318	32.48	1.66	19.20
2	12.5	SW	*Salix spp.*	10.8	12.2	0.2		34	2	91.6	0.0	6.66	0.0494	NA	319	218.32	0.15	10.79
2	12.5	SW	*Picea mariana*	16.7	16.06	1.4		65	2	219.0	0.0	67.29	0.1771	0.1673	320	91.31	0.61	16.17
2	12.5	SW	*Picea glauca*	15.8	15.4	2.2		60	2	196.1	0.0	94.00	0.1338	0.1314	321	102.01	0.96	13.65
2	12.5	SW	*Picea mariana*	20.6	12.6	1		52	2	333.3	0.0	61.58	0.1817	0.1902	322	60.01	0.37	10.91
2	12.5	SW	*Picea glauca*	21	16.8	4.1		58	2	346.4	0.0	217.68	0.2509	0.2492	323	57.74	1.26	14.49
2	12.5	SW	*Populus tremuloides*	39.4	24.38	10.4		54	2	1219.2	0.0	947.50	1.2016	1.3080	324	16.40	1.55	19.71
2	12.5	SW	*Populus tremuloides*	21.8	22.22	6		68	2	373.3	0.0	297.82	0.3560	0.3633	325	53.58	1.60	19.02
2	12.5	SW	*Picea glauca*	30.6	25.44	4		53	2	735.4	0.0	334.27	0.7769	0.7306	326	27.20	0.91	21.18
2	12.5	SW	*Populus tremuloides*	25.3	22.4	5.2		53	2	502.7	0.0	328.36	0.4753	0.4935	327	39.78	1.31	18.91
2	65	C	*Populus balsamifera*	14.5	15.8	0.4		32	3	165.1	0.0	17.72	0.0973	0.1125	286	181.68	0.32	17.68
2	65	C	*Picea glauca*	35.6	26.75	3.2		78	3	995.4	0.0	325.72	1.0863	1.0260	287	30.14	0.98	32.74
2	65	C	*Picea glauca*	29.2	23.92	1		59	3	669.7	0.0	88.59	0.6700	0.6353	288	44.80	0.40	30.02
2	65	C	*Picea mariana*	22.1	19.58	1		73	3	383.6	0.0	66.29	0.3243	0.3118	289	78.21	0.52	25.37
2	65	C	*Picea glauca*	18.3	19.32	2.2		65	3	263.0	0.0	111.28	0.2231	0.2117	290	114.06	1.27	25.45
2	65	C	*Picea glauca*	28.9	21.36	3.8		63	3	656.0	0.0	299.65	0.5842	0.5709	291	45.73	1.37	26.72
2	65	C	*Populus tremuloides*	30.6	23	5			3	735.4	0.0	402.12	0.6999	0.7423	292	40.79	1.64	28.55
2	65	C	*Populus tremuloides*	35.4	26.64	9.8		67	3	984.2	0.0	788.16	1.0748	1.1612	293	30.48	2.40	32.76
2	65	C	*Picea mariana*	19.6	25.52	2.2		56	3	301.7	0.0	120.26	0.3404	0.2984	294	99.43	1.20	33.85
2	65	C	*Picea glauca*	28	24.15	3.2		66	3	615.8	0.0	249.32	0.6254	0.5684	295	48.72	1.21	30.47
2	65	C	*Picea glauca*	30.3	25.53	4		63	3	721.1	0.0	330.50	0.7676	0.7161	296	41.61	1.38	31.94
2	65	C	*Picea glauca*	24.8	23.46	3		61	3	483.1	0.0	205.46	0.4837	0.4516	297	62.11	1.26	30.04
2	65	C	*Populus tremuloides*	29.7	24.84	3.3		57	3	692.8	0.0	273.70	0.7166	0.7587	298	43.30	1.19	31.04
2	65	C	*Picea glauca*	14.8	15.4	4		48	3	172.0	0.0	135.72	0.1181	0.1153	299	174.38	2.37	20.80
2	65	C	*Populus tremuloides*	33.7	23.52	7.2			3	892.0	0.0	599.42	0.8612	0.9219	300	33.63	2.02	28.96
2	65	NE	*Populus tremuloides*	32.8	26.78	8.6		73	3	845.0	0.0	653.83	0.8349	1.0025	301	35.50	2.32	33.19
2	65	NE	*Picea glauca*	27.5	24.08	4.8		59	3	594.0	0.0	342.31	0.6029	0.5663	302	50.51	1.73	30.45
2	65	NE	*Picea glauca*	35.6	26.75	3.2		78	3	995.4	0.0	325.72	1.0863	1.0260	303	30.14	0.98	32.74
2	65	NE	*Populus tremuloides*	33.7	23.52	7.2			3	892.0	0.0	599.42	0.8612	0.9219	304	33.63	2.02	28.96
2	65	NE	*Populus tremuloides*	49.1	26.04	7.3			3	1893.4	0.0	958.63	1.9509	2.1803	305	15.84	1.52	30.91
2	65	NE	*Picea glauca*	16.9	15.6	2.2		43	3	224.3	0.0	101.60	0.1541	0.1519	306	133.74	1.36	20.61
2	65	NE	*Populus tremuloides*	29.4	26.25	3.4			3	678.9	0.0	277.72	0.7436	0.7884	307	44.19	1.23	32.87
2	65	NE	*Populus tremuloides*	26.5	23.92	5.8		60	3	561.5	0.0	377.18	0.5553	0.5803	308	54.39	2.05	30.21
2	65	NE	*Populus balsamifera*	21.4	22.4				3	359.7	0.0	0.00	0.2915	0.3531	309	83.41	0.00	24.32
2	65	NE	*Picea glauca*	32.7	21.34	6		63	3	839.8	0.0	503.28	0.7343	0.7304	310	35.72	1.80	26.23
2	65	NE	*Populus tremuloides*	42.9	30.72	12		93	3	1445.5	0.0	1164.90	1.7923	1.9868	311	20.75	2.42	37.20
2	65	NE	*Populus tremuloides*	38.1	21.12	7		67	3	1140.1	0.0	683.92	0.9723	1.0519	312	26.31	1.80	25.59
2	65	SW	*Populus tremuloides*	29.9	20.16	8.9		67	3	702.2	0.0	587.16	0.5857	0.6169	272	42.73	2.51	25.03
2	65	SW	*Populus tremuloides*	30.2	22.54	8.6			3	716.3	0.0	583.58	0.6695	0.7078	273	41.88	2.44	28.04
2	65	SW	*Populus tremuloides*	31.8	22.54	7.2		67	3	794.2	0.0	566.44	0.7384	0.7848	274	37.77	2.10	27.88
2	65	SW	*Picea glauca*	18.3	13	2.8		63	3	263.0	0.0	136.35	0.1475	0.1530	275	114.06	1.56	16.82
2	65	SW	*Picea glauca*	23.9	23.1	2.1		67	3	448.6	0.0	143.82	0.4440	0.4146	276	66.87	0.96	29.69
2	65	SW	*Populus tremuloides*	35.4	26.64	9.8		67	3	984.2	0.0	788.16	1.0748	1.1612	277	30.48	2.40	32.76

Appendix IV. PSP Data

Toposequence	Transect Position	Plot	Species	dhbob (cm)	Height (m)	Sapwood Radius (cm)	Bark Thickness (cm)	Age (years)	BAF	Total BA (cm^2) bhob	Bark Area (cm^2) bh	Sapwood Area (cm^2)	Shongming's Taper Individual Tree Volumes (m^3)	Honer's Equation Individual Tree Volumes (m^3)	Original Order	Stand Table Factor (STF) (number of trees/ha represented by sampled tree)	using STF Sapwood Area (m^2/ha)	using STF Tree Volume (Shongming's Taper Model) (m^3/ha)
2	65	SW	*Picea glauca*	31.2	22.36	3.2		68	3	764.5	0.0	281.49	0.7063	0.6892	278	39.24	1.10	27.72
2	65	SW	*Populus tremuloides*	19.3	20.52	4.2		48	3	292.6	0.0	199.24	0.2597	0.2619	279	102.55	2.04	26.63
2	65	SW	*Picea glauca*	21	16.02	4		72	3	346.4	0.0	213.63	0.2386	0.2397	280	86.61	1.85	20.67
2	65	SW	*Picea mariana*	24.4	17.4	1.1		66	3	467.6	0.0	80.52	0.3456	0.3468	281	64.16	0.52	22.17
2	65	SW	*Picea mariana*	19.9	14.6	1.8		56	3	311.0	0.0	102.35	0.1977	0.2004	282	96.46	0.99	19.07
2	65	SW	*Picea glauca*	20.7	17.82	0.8		62	3	336.5	0.0	50.01	0.2594	0.2539	283	89.14	0.45	23.12
2	65	SW	*Populus tremuloides*	16.9	16.2	4		40	3	224.3	0.0	162.11	0.1565	0.1568	284	133.74	2.17	21.20
2	65	SW	*Populus tremuloides*	15.9	13.2	2.1		44	3	198.6	0.0	91.04	0.1146	0.1123	285	151.09	1.38	17.32
2	110	C	*Picea mariana*	6.3	7.2	1		36	3	31.2	0.0	16.65	0.0114	0.0109	247	962.39	1.60	10.98
2	110	C	*Picea mariana*	14.4	13.56	1.9		52	3	162.9	0.0	71.25	0.1004	0.0988	248	184.21	1.31	18.50
2	110	C	*Picea mariana*	8.9	12	1.2		46	3	62.2	0.0	29.03	0.0357	0.0341	249	482.23	1.40	17.20
2	110	C	*Picea mariana*	15.3	13.86	2.6		54	3	183.9	0.0	103.74	0.1151	0.1136	250	163.17	1.69	18.78
2	110	C	*Picea mariana*	11.9	13.02	1.6		46	3	111.2	0.0	51.77	0.0675	0.0652	251	269.74	1.40	18.20
2	110	C	*Picea mariana*	8.8	11.2	1		47	3	60.8	0.0	24.50	0.0331	0.0314	252	493.25	1.21	16.30
2	110	C	*Picea mariana*	9.5	10.5	1		46	3	70.9	0.0	26.70	0.0358	0.0347	253	423.24	1.13	15.14
2	110	C	*Picea mariana*	12.7	13.44	1.8		54	3	126.7	0.0	61.64	0.0787	0.0763	254	236.82	1.46	18.65
2	110	C	*Picea mariana*	16.3	15.2	3.2		60	3	208.7	0.0	131.70	0.1419	0.1389	255	143.77	1.89	20.40
2	110	C	*Populus balsamifera*	23.1	18.24	6.4		61	3	419.1	0.0	335.77	0.2759	0.3316	256	71.58	2.40	19.75
2	110	C	*Picea mariana*	19.6	18.24	3.8		70	3	301.7	0.0	188.62	0.2410	0.2322	257	99.43	1.88	23.97
2	110	C	*Picea mariana*	10.7	12.06	2		44	3	89.9	0.0	54.66	0.0512	0.0495	258	333.63	1.82	17.10
2	110	C	*Picea mariana*	11.4	13.09	1.6		46	3	102.1	0.0	49.26	0.0627	0.0601	259	293.91	1.45	18.41
2	110	NE	*Picea mariana*	30.5	20.7	2		130	3	730.6	0.0	179.07	0.6266	0.6196	230	41.06	0.74	25.73
2	110	NE	*Picea mariana*	14.4	14.22	1.4		90	3	162.9	0.0	57.18	0.1053	0.1027	231	184.21	1.05	19.39
2	110	NE	*Picea mariana*	18.5	18	2		78	3	268.8	0.0	103.67	0.2125	0.2047	232	111.61	1.16	23.71
2	110	NE	*Picea mariana*	16.5	14.94	1.6		133	3	213.8	0.0	74.90	0.1430	0.1404	233	140.30	1.05	20.06
2	110	NE	*Picea mariana*	20.8	17.08	0.8		127	3	339.8	0.0	50.27	0.2517	0.2463	234	88.29	0.44	22.22
2	110	NE	*Picea mariana*	17.5	14	1.8		83	3	240.5	0.0	88.78	0.1478	0.1498	235	124.73	1.11	18.44
2	110	NE	*Picea mariana*	14.8	15.12	4		56	3	172.0	0.0	135.72	0.1179	0.1141	236	174.38	2.37	20.56
2	110	NE	*Picea mariana*	24	19.6	3.2		58	3	452.4	0.0	209.10	0.3787	0.3680	237	66.31	1.39	25.11
2	110	NE	*Picea mariana*	16.2	14.96	1.8		59	3	260.2	0.0	92.74	0.1718	0.1710	238	115.32	1.07	19.82
2	110	NE	*Picea mariana*	20	17.28	1.4		74	3	314.2	0.0	81.81	0.2368	0.2317	239	95.49	0.78	22.61
2	110	NE	*Picea mariana*	24	18	2.1		90	3	452.4	0.0	144.48	0.3454	0.3445	240	66.31	0.96	22.91
2	110	NE	*Picea mariana*	18.6	17.28	2		127	3	271.7	0.0	104.30	0.2069	0.2004	241	110.41	1.15	22.84
2	110	NE	*Picea mariana*	21.1	19.6	1.7		99	3	349.7	0.0	103.61	0.2979	0.2844	242	85.80	0.89	25.55
2	110	NE	*Picea mariana*	22.1	17.29	1.4		114	3	383.6	0.0	91.04	0.2854	0.2831	243	78.21	0.71	22.32
2	110	NE	*Picea mariana*	20.6	18.62	1.4		114	3	333.3	0.0	84.45	0.2703	0.2606	244	90.01	0.76	24.33
2	110	NE	*Picea mariana*	7.9	9.54	0.6		74	3	49.0	0.0	13.76	0.0231	0.0221	245	612.04	0.84	14.12
2	110	NE	*Picea mariana*	14.4	12.92	1.6		80	3	162.9	0.0	64.34	0.0958	0.0949	246	184.21	1.19	17.65
2	110	SW	*Picea mariana*	16	14.04	1.4		56	3	201.1	0.0	64.21	0.1264	0.1255	260	149.21	0.96	18.86
2	110	SW	*Picea mariana*	20.5	15.36	1		56	3	330.1	0.0	61.26	0.2199	0.2216	261	90.89	0.56	19.98
2	110	SW	*Picea mariana*	8.2	9.9	1.4		56	3	52.8	0.0	29.91	0.0258	0.0245	262	568.07	1.70	14.63
2	110	SW	*Picea mariana*	6.9	9.5	1		52	3	37.4	0.0	18.54	0.0178	0.0168	263	802.29	1.49	14.32
2	110	SW	*Picea mariana*	16.1	14.55	1.1		43	3	203.6	0.0	51.84	0.1327	0.1308	264	147.36	0.76	19.56
2	110	SW	*Picea mariana*	22.8	14.25	1		66	3	408.3	0.0	68.49	0.2485	0.2580	265	73.48	0.50	18.26
2	110	SW	*Populus tremuloides*	33.9	19.62	3.8	1	69	3	902.6	103.4	255.98	0.7227	0.7707	266	33.24	0.85	24.02
2	110	SW	*Populus tremuloides*	31.7	19.8	11.2	0.6	95	3	789.2	58.6	662.69	0.6427	0.6804	267	38.01	2.52	24.43
2	110	SW	*Picea mariana*	13.5	12.32	1.2		54	3	143.1	0.0	46.37	0.0807	0.0802	268	209.59	0.97	16.92
2	110	SW	*Picea mariana*	6.4	8.9	0.8		56	3	32.2	0.0	14.07	0.0146	0.0136	269	932.55	1.31	13.64
2	110	SW	*Picea mariana*	9.9	8.5	1.6		47	3	77.0	0.0	41.72	0.0313	0.0313	270	389.73	1.63	12.19
2	110	SW	*Picea mariana*	10.2	11.83	1.1		54	3	81.7	0.0	31.45	0.0461	0.0442	271	367.14	1.15	16.94

Appendix IV. PSP Data

Toposequence	Transect Position	Plot	Species	dhbob (cm)	Height (m)	Sapwood Radius (cm)	Bark Thickness (cm)	Age (years)	BAF	Total BA (cm^2) bhob	Bark Area (cm^2) bh	Sapwood Area (cm^2)	Shongming's Taper Individual Tree Volumes (m^3)	Honer's Equation Individual Tree Volumes (m^3)	Original Order	Stand Table Factor (STF) (number of tree/ha represented by sampled tree)	using STF Sapwood Area (m^2/ha)	using STF Tree Volume (Shongming's Taper Model) (m^3/ha)
3	10	C	*Betula papyrifera*	10.9	12.45	3.7	0.3	29	2	93.3	10.0	73.70	0.0514	0.0536	210	214.33	1.58	11.01
3	10	C	*Pinus contorta*	32.4	20	5.6	0.6	36	2	824.5	59.9	411.55	0.7336	0.7324	211	24.26	1.00	17.80
3	10	C	*Picea mariana*	20.2	12.75	2.4	0.6	40	2	320.5	36.9	97.26	0.1774	0.1847	212	62.41	0.61	11.07
3	10	C	*Picea glauca*	13.3	10.08	2.8	0.5	35	2	138.9	20.1	72.26	0.0825	0.0649	213	143.96	1.04	9.00
3	10	C	*Populus tremuloides*	11.9	12.9	3.2	0.3	40	2	111.2	10.9	76.53	0.0647	0.0614	214	179.82	1.36	11.64
3	10	C	*Populus balsamifera*	10.4	10.2	1.6	0.5	27	2	84.9	15.6	28.68	0.0336	0.0369	215	235.44	0.68	7.90
3	10	C	*Populus balsamifera*	11.7	10	1.6	0.4	55	2	107.5	14.2	36.57	0.0406	0.0457	216	188.02	0.68	7.56
3	10	C	*Populus tremuloides*	16.2	14.42	2.6	0.4	33	2	206.1	19.9	91.23	0.1300	0.1277	217	97.03	0.89	12.61
3	10	C	*Picea mariana*	13	11.1	1.8	0.2	28	2	132.7	8.0	55.29	0.0677	0.0681	218	150.68	0.83	10.20
3	10	C	*Populus balsamifera*	10.2	11.88	1.2	0.4		2	81.7	12.3	21.61	0.0377	0.0415	219	244.76	0.53	9.22
3	10	C	*Picea mariana*	16.6	12.96	1.4	0.4	41	2	216.4	20.4	46.50	0.1252	0.1265	220	92.41	0.43	11.57
3	10	C	*Picea mariana*	16	13.14	1.1	0.2	42	2	201.1	9.9	41.56	0.1182	0.1188	221	99.47	0.41	11.76
3	10	C	*Picea mariana*	14.4	12.78	2	0.6	32	2	162.9	26.0	51.90	0.0947	0.0941	222	122.80	0.64	11.63
3	10	C	*Picea mariana*	21.1	14.4	4	0.4	48	2	349.7	26.0	188.87	0.2173	0.2228	223	57.20	1.08	12.43
3	10	E	*Populus tremuloides*	19.2	17.28	5.6	0.4	48	2	289.5	23.6	215.64	0.2158	0.2165	196	69.08	1.49	14.91
3	10	E	*Betula papyrifera*	5.7	6.27	1	0.2		2	25.5	3.5	11.31	0.0074	0.0083	197	783.77	0.89	5.84
3	10	E	*Populus tremuloides*	20.4	18.7	6.5	0.5	61	2	326.9	31.3	252.58	0.2626	0.2654	198	61.19	1.55	16.07
3	10	E	*Picea mariana*	23.4	14.72	2.4	0.6	40	2	430.1	43.0	115.36	0.2698	0.2790	199	46.51	0.54	12.55
3	10	E	*Populus tremuloides*	20.3	17.82	6	0.6	53	2	323.7	37.1	232.42	0.2478	0.2499	200	61.79	1.44	15.31
3	10	E	*Populus tremuloides*	13.4	14.08	3.6	0.4	37	2	141.0	16.3	94.50	0.0884	0.0853	201	141.82	1.34	12.53
3	10	E	*Picea mariana*	18.7	14.4	2.8	0.4	35	2	274.6	23.0	116.87	0.1735	0.1750	202	72.82	0.85	12.63
3	10	E	*Picea mariana*	13.4	11.1	2.2	0.3	35	2	141.0	12.3	65.06	0.0716	0.0723	203	141.82	0.92	10.16
3	10	E	*Picea mariana*	18.9	13.56	2.4	0.4	40	2	280.6	23.2	101.16	0.1668	0.1704	204	71.29	0.72	11.89
3	10	E	*Betula papyrifera*	7.6	9.5	1.7	0.3	27	2	45.4	6.9	24.63	0.0196	0.0210	205	440.87	1.09	8.64
3	10	E	*Populus tremuloides*	24	18.7	5.6	0.6	46	2	452.4	44.1	279.60	0.3576	0.3674	206	44.21	1.24	15.81
3	10	E	*Picea glauca*	9.8	11.52	2.2	0.3	33	2	75.4	9.0	43.57	0.0400	0.0396	207	265.15	1.16	10.59
3	10	E	*Populus balsamifera*	28.5	16	8.6	0.3	56	2	637.9	26.6	511.07	0.3651	0.4403	208	31.35	1.60	11.45
3	10	E	*Picea mariana*	27	15.36	7	0.6	43	2	572.6	49.8	390.06	0.3679	0.3845	209	34.93	1.36	12.85
3	10	W	*Picea mariana*	20.4	12.45	2.8	0.3	37	2	326.9	18.9	135.87	0.1762	0.1847	224	61.19	0.83	10.78
3	10	W	*Picea mariana*	18.1	12.9	2	0.4	40	2	257.3	22.2	78.92	0.1464	0.1498	225	77.73	0.61	11.38
3	10	W	*Picea glauca*	10.9	10.2	3.7	0.4	20	2	93.3	13.2	70.50	0.0433	0.0440	226	214.33	1.51	9.27
3	10	W	*Picea glauca*	27.7	16.4	5	0.6	35	2	602.6	51.1	306.49	0.4112	0.4252	227	33.19	1.01	13.66
3	10	W	*Picea mariana*	16.3	13.8	2	0.3	40	2	208.7	15.1	74.77	0.1269	0.1284	228	95.84	0.72	12.35
3	10	W	*Picea mariana*	12	10.05	2.1	0.2	27	2	113.1	7.4	57.90	0.0528	0.0533	229	176.84	1.02	9.33
3	75	C	*Populus tremuloides*	9.5	0.56	0.6	0.4		4	70.9	11.4	5.34	0.0149	0.0017	177	564.32	0.30	8.40
3	75	C	*Populus tremuloides*	17.3	17.64	5.2	0.4	60	4	235.1	21.2	176.43	0.1808	0.1796	178	170.17	3.00	30.77
3	75	C	*Populus tremuloides*	16.1	16.38	2.7	0.5	54	4	203.6	24.5	89.16	0.1462	0.1440	179	196.48	1.75	28.72
3	75	C	*Populus tremuloides*	17.2	20.46	4	0.5	56	4	232.4	26.2	139.64	0.2079	0.2073	180	172.15	2.40	35.78
3	75	C	*Populus tremuloides*	18.7	21.12	5.1	0.3	52	4	274.6	17.3	200.56	0.2517	0.2534	181	145.64	2.92	36.66
3	75	C	*Picea glauca*	12.3	11.36	1.2	0.4	43	4	118.8	15.0	26.89	0.0608	0.0616	182	336.64	0.91	20.48
3	75	C	*Populus tremuloides*	20.5	20.68	3.1	0.3	56	4	330.1	19.0	150.42	0.2936	0.2979	183	121.19	1.82	35.59
3	75	C	*Populus tremuloides*	27.7	24.86	1	0.4	58	4	602.6	34.3	49.57	0.6284	0.6805	184	66.38	0.33	41.71
3	75	E	*Picea glauca*	7.8	3.08	1.9	0.4	41	4	47.8	9.3	25.92	0.0073	0.0074	185	837.11	2.17	6.12
3	75	E	*Populus tremuloides*	30.9	21.42	4	1	76	4	749.9	93.9	244.10	0.6636	0.7022	186	53.34	1.30	35.39
3	75	E	*Populus tremuloides*	32.1	23.32	5	0.4	68	4	809.3	39.8	385.85	0.7764	0.8289	187	49.43	1.91	38.47
3	75	E	*Picea glauca*	8.3	9	1.4	0.3	38	4	54.1	7.5	22.81	0.0221	0.0229	188	739.29	1.69	16.31
3	75	E	*Populus tremuloides*	46.3	24	5.6	0.8		4	1683.7	114.4	601.68	1.6031	1.7778	189	23.76	1.43	38.09
3	75	E	*Populus tremuloides*	30.6	23.4	6.4	0.4	77	4	735.4	38.0	448.62	0.7133	0.7560	190	54.39	2.44	38.80
3	75	E	*Populus tremuloides*	29.3	23.4	6.2	0.6	80	4	674.3	54.1	395.84	0.6569	0.6931	191	59.32	2.35	38.97
3	75	E	*Populus tremuloides*	6.7	8.25	1.2	0.3	19	4	35.3	6.0	14.70	0.0138	0.0123	192	1134.54	1.67	15.64

Appendix IV. PSP Data

Toposequence	Transect Position	Plot	Species	dhbob (cm)	Height (m)	Sapwood Radius (cm)	Bark Thickness (cm)	Age (years)	BAF	Total BA (cm^2) bhob	Bark Area (cm^2) bh	Sapwood Area (cm^2)	Shongming's Taper Individual Tree Volumes (m^3)	Honer's Equation Individual Tree Volumes (m^3)	Original Order	Stand Table Factor (STF) (number of trees/ha represented by sampled tree)	using STF Sapwood Area (m^2/ha)	using STF Tree Volume (Shongming's Taper Model) (m^3/ha)
3	75	E	*Picea glauca*	10	9.76	1.8	0.3	50	4	78.5	9.1	37.23	0.0352	0.0356	193	809.30	1.90	17.94
3	75	E	*Picea glauca*	15.2	14.24	2.8	0.4	41	4	181.5	18.6	90.48	0.1147	0.1139	194	220.44	1.99	25.26
3	75	E	*Populus tremuloides*	27.7	23.2	6.6	0.8	79	4	602.6	67.6	369.89	0.5852	0.6139	195	68.38	2.46	38.84
3	75	W	*Populus tremuloides*	13.7	11.05	3.2	0.4	45	4	147.4	16.7	88.84	0.0721	0.0694	170	271.35	2.41	19.57
3	75	W	*Picea mariana*	14.2	14.84	2	0.4	37	4	156.4	17.3	59.31	0.1073	0.1034	171	262.58	1.50	27.11
3	75	W	*Picea mariana*	7.9	8.96	0.8	0.4	29	4	49.0	9.4	8.42	0.0218	0.0209	172	816.05	0.69	17.79
3	75	W	*Picea glauca*	14.7	13.72	1.8	0.4	40	4	169.7	18.0	54.98	0.1037	0.1033	173	235.69	1.30	24.45
3	75	W	*Picea mariana*	17.1	12.45	2	0.4	48	4	229.7	21.0	73.89	0.1268	0.1298	174	174.17	1.29	22.08
3	75	W	*Populus tremuloides*	28.7	24.64	13.2	0.5	67	4	646.9	44.3	598.47	0.6660	0.7024	175	61.63	3.70	41.18
3	75	W	*Populus tremuloides*	31.7	21.58	5.2	0.8	65	4	789.2	77.7	355.25	0.7013	0.7441	176	90.68	1.80	36.54
3	125	C	*Picea mariana*	8.8	10.06	1.1	0.3	45	4	60.8	8.0	18.60	0.0297	0.0287	151	867.67	1.22	19.51
3	125	C	*Picea glauca*	6.3	6.3	0.8	0.5	31	4	31.2	9.1	4.71	0.0093	0.0095	152	1283.18	0.60	11.94
3	125	C	*Picea glauca*	9	8.9	1.3	0.3	34	4	63.6	8.2	23.25	0.0263	0.0266	153	628.76	1.46	16.54
3	125	C	*Picea mariana*	13.5	12.74	1.6	0.4	44	4	143.1	16.5	43.35	0.0837	0.0824	154	279.45	1.21	23.38
3	125	C	*Picea mariana*	14.5	12.45	2.3	0.4	47	4	165.1	17.7	70.43	0.0932	0.0933	155	242.23	1.71	22.59
3	125	C	*Picea mariana*	8.4	9.49	1	0.3	41	4	55.4	7.6	15.61	0.0257	0.0248	156	721.79	1.13	18.56
3	125	C	*Picea mariana*	9.9	10.82	1.6	0.3	45	4	77.0	9.0	32.67	0.0399	0.0388	157	519.64	1.70	20.74
3	125	C	*Picea glauca*	11.2	11.94	1.4	0.3	46	4	98.5	10.3	32.83	0.0537	0.0533	158	406.01	1.33	21.80
3	125	C	*Picea glauca*	8.7	10.82	1.3	0.4	45	4	59.4	10.4	19.79	0.0299	0.0296	159	672.87	1.33	20.13
3	125	C	*Picea glauca*	21.5	16.74	0.8	0.6	50	4	363.1	39.4	12.63	0.2612	0.2606	160	110.18	0.14	28.78
3	125	C	*Picea mariana*	5.6	7.54	1	0.2	38	4	24.6	3.4	11.06	0.0096	0.0090	161	1624.03	1.80	15.63
3	125	C	*Picea mariana*	9.5	10.92	1.1	0.3	44	4	70.9	8.7	20.36	0.0373	0.0358	162	564.32	1.15	21.06
3	125	E	*Picea mariana*	16.6	12.5	2.4	0.4	43	4	216.4	20.4	86.71	0.1205	0.1227	146	184.82	1.60	22.26
3	125	E	*Picea mariana*	12.3	12.45	2.2	0.3	49	4	118.8	11.3	58.50	0.0687	0.0671	147	336.64	1.97	23.11
3	125	E	*Picea glauca*	20.6	16.64	4.4	0.5	52	4	333.3	31.6	192.36	0.2395	0.2379	148	120.02	2.31	28.74
3	125	E	*Larix laricina*	37.3	21.22	2.5	0.6	94	4	1092.7	69.2	204.14	0.9566	NA	149	36.61	0.75	35.02
3	125	E	*Picea mariana*	35.5	16.92	2.5	1	77	4	989.8	108.4	150.60	0.6796	0.7181	150	40.41	0.61	27.46
3	125	W	*Picea mariana*	7.4	8.16	1.2	0.4	33	4	43.0	8.8	14.58	0.0174	0.0169	163	930.06	1.36	16.21
3	125	W	*Picea mariana*	17.5	13.2	2	0.4	50	4	240.5	21.5	75.90	0.1403	0.1427	164	166.30	1.26	23.34
3	125	W	*Picea mariana*	9.3	10.2	1.6	0.3	36	4	67.9	8.5	30.22	0.0333	0.0324	165	588.85	1.78	19.64
3	125	W	*Picea mariana*	11.5	10.9	2	0.3	41	4	103.9	10.6	49.13	0.0532	0.0524	166	385.10	1.89	20.46
3	125	W	*Picea mariana*	13.4	11.7	2.1	0.3	39	4	141.0	12.3	62.20	0.0757	0.0756	167	293.64	1.76	21.48
3	125	W	*Pinus contorta*	13.3	14.1	2.8	0.4	40	4	138.9	16.2	76.15	0.0986	0.0900	168	287.92	2.19	28.39
3	125	W	*Picea mariana*	14.3	11.34	2.4	0.3	42	4	160.6	13.2	76.53	0.0827	0.0839	169	249.06	1.91	20.59
3	275	C	*Picea mariana*	26.6	17.64	0.8	0.5	112	2	565.7	41.0	23.84	0.4119	0.4166	129	35.99	0.09	14.82
3	275	C	*Picea mariana*	25.7	16.34	1.5	0.5	89	2	518.7	39.6	74.46	0.3571	0.3661	130	38.55	0.29	13.77
3	275	C	*Picea mariana*	21.1	15.2	1.4	0.6	81	2	349.7	36.6	46.00	0.2295	0.2328	131	57.20	0.27	13.13
3	275	C	*Picea mariana*	17.2	15.2	0.5	0.3	64	2	232.4	15.9	10.30	0.1568	0.1547	132	86.08	0.09	13.50
3	275	C	*Larix laricina*	14.4	11.48	1.5	0.4	84	2	162.9	17.6	43.20	0.0968	NA	133	122.80	0.53	10.66
3	275	C	*Picea mariana*	21.8	16.15	0.5	0.6	68	2	373.3	40.0	-6.50	0.2595	0.2609	134	53.58	-0.03	13.90
3	275	E	*Larix laricina*	4	4.74	1.7	0.2	15	2	12.6	2.4	9.90	0.0031	NA	135	1591.56	1.58	4.93
3	275	E	*Picea mariana*	20.7	15.88	0.9	0.6	84	2	336.5	37.9	18.10	0.2319	0.2321	136	59.43	0.11	13.78
3	275	E	*Picea mariana*	20.8	16.72	0.8	0.4	100	2	339.8	25.6	24.63	0.2405	0.2442	137	58.86	0.14	14.51
3	275	E	*Picea mariana*	15.3	11.56	2.8	0.4	104	2	183.9	18.7	91.23	0.0967	0.0976	138	108.78	0.99	10.41
3	275	E	*Picea mariana*	12.4	10.45	1	0.2	97	2	120.8	7.7	28.15	0.0584	0.0588	139	165.61	0.47	9.68
3	275	E	*Picea mariana*	22.4	14.4	2	0.5	152	2	394.1	34.4	93.78	0.2430	0.2511	140	50.75	0.48	12.33
3	275	E	*Picea mariana*	21.7	15.58	1.1	0.3	151	2	369.8	20.2	51.02	0.2482	0.2512	141	54.06	0.28	13.42
3	275	E	*Picea mariana*	17.8	14.04	0.6	0.6	95	2	248.8	32.4	0.00	0.1542	0.1563	142	80.37	0.00	12.39
3	275	E	*Picea mariana*	14.1	12.06	1.2	0.4	112	2	156.1	17.2	31.42	0.0856	0.0859	143	128.09	0.40	10.97
3	275	E	*Picea mariana*	13.4	12.24	0.7	0.3	99	2	141.0	12.3	15.58	0.0791	0.0786	144	141.82	0.22	11.22

Appendix IV. PSP Data

Toposequence	Transect Position	Plot	Species	dhbob (cm)	Height (m)	Sapwood Radius (cm)	Bark Thickness (cm)	Age (years)	BAF	Total BA (cm^2) bhob	Bark Area (cm^2) bh	Sapwood Area (cm^2)	Shongming's Taper Individual Tree Volumes (m^3)	Honer's Equation Individual Tree Volumes (m^3)	Original Order	Stand Table Factor (STF) (number of tree/ha represented by sampled tree)	using STF Sapwood Area (m^2/ha)	using STF Tree Volume (Shongming's Taper Model) (m^3/ha)
3	275	E	*Picea mariana*	19.9	16.92	1	0.4	158	2	311.0	24.5	34.87	0.2300	0.2256	145	64.30	0.22	14.79
3	275	W	*Picea mariana*	6.1	5.63	1.2	0.3	28	4	29.2	5.5	13.01	0.0089	0.0085	121	1368.71	1.78	12.17
3	275	W	*Larix laricina*	8.5	7.2	0.6	0.2	75	4	56.7	5.2	9.68	0.0197	NA	122	704.91	0.68	13.89
3	275	W	*Picea mariana*	7.4	7.1	1.5	0.2	32	4	43.0	4.5	23.28	0.0152	0.0149	123	930.05	2.17	14.12
3	275	W	*Larix laricina*	5.2	6.05	0.8	0.3	44	4	21.2	4.6	6.44	0.0064	NA	124	1883.49	1.21	12.07
3	275	W	*Larix laricina*	5.7	6.05	0.1	0.2	60	4	25.5	3.5	-1.70	0.0077	NA	125	1567.55	-0.27	11.99
3	275	W	*Larix laricina*	6.8	6.71	1.4	0.4	43	4	36.3	8.0	15.71	0.0121	NA	126	1101.42	1.73	13.30
3	275	W	*Larix laricina*	8.4	4.5	0.4	0.3	41	4	55.4	7.6	2.42	0.0123	NA	127	721.79	0.17	8.86
3	275	W	*Larix laricina*	8.5	7.1	0.4	0.2	75	4	56.7	5.2	4.96	0.0194	NA	128	704.91	0.35	13.68

APPENDIX V

Plant Community and Structure

Plant community structure and composition was described using percentage cover. The collection of plant community structure and composition data was accomplished during the period from 11 August 1998 to 31 August 1998. Percentage cover was estimated for forbs and mosses/lichen within four $1m^2$ sub-samples from randomly selected positions within each 10m by 10m plot. Tree and shrub cover estimates were determined from the same 10 m^2 plots.

The forb layer includes "all herbaceous plants exclusive of graminoids generally less than 25 cm tall" (Beckingham *et al.*, 1996). The moss/lichen layer includes moss which is a "small, leafy plant lacking any true vascular system or roots" (Beckingham *et al.*, 1996). The tree layer is defined by species in "uppermost canopy (>5m) or in the understory provided that they are greater than 5 m tall. The shrub layer is composed of "woody perennials occupying the stratum from ground level to 5 m in height" (Beckingham *et al.*, 1996). The plants that could not be readily identified in the field were numbered, and a specimen taken in a plant press for later identification.

Plant community and structure information was used with the Field guide to ecosites of west-central Alberta to classify ecosite, ecophase, and plant community type. Only the rigor necessary for site classification was used in collecting the plant community and structure data.

Literature Cited

Beckingham, J. D., I. G. W. Corns, and J. H. Archibald. 1996. Field guide to ecosites of west-central Alberta. Edmonton, Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent. Special Report 9.

References

Johnson, D., L. Kershaw, A. MacKinnon, and J. Pojar. 1995. Plants of the western boreal forest and aspen parkland. Lone Pine, Edmonton, Alberta. 392 pp.

Moss, E. H. 1996. Flora of Alberta. 2nd. University of Toronto Press, Toronto, Ontario. 687 pp.

Toposequence: 1
Transect Position: 35m
Plot No.: C

Date: 12-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea glauca					3
Populus balsamifera					1
Populus tremuloides					20
Shrubs					**%**
Alnus crispa					25
Cornus stolonifera					10
Ledum groenlandicum					<1
Lonicera involucrata					1
Picea glauca					1
Ribes oxyacanthoides					1
Rosa acicularis					2
Spiraea betulifolia					4
Viburnum edule					7
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Aster conspicuus	0	0	2	1	1
Cornus canadensis	8	7	5	1	5
Epilobium angustifolium	0	0	0	1	0
Fragaria virginiana	0	0	1	1	1
Galium triflorum	2	0	1	0	1
Liliaceae	0	0	1	1	1
Galium boreale	0	0	6	0	2
Osmorhiza depauperata	0	<1	0	0	0
Petasites palmatus	<1	0	2	0	1
Pyrola asarifolia	0	2	1	<1	1
Rubus pubescens	1	3	6	2	3
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	0	0	4	1	1
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Eurhynchium pulchellum	4	2	0	8	4

Toposequence: 1
Transect Position: 35m
Plot No.: E

Date: 12-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea glauca					2
Populus tremuloides					20
Shrubs					**%**
Alnus crispa					10
Cornus stolonifera					5
Lonicera involucrata					8
Picea glauca					1
Populus tremuloides					<1
Ribes oxyacanthoides					1
Rosa acicularis					2
Salix planifolia					1
Viburnum edule					10
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Aster conspicuus	0	0	1	0	0
Cornus canadensis	2	<1	10	4	5
Fragaria virginiana	1	0	1	<1	1
Galium triflorum	<1	<1	<1	0	0
Lathyrus ochroleucus	<1	1	0	0	0
Liliaceae	2	0	0	0	1
Linnaea borealis	<1	1	2	0	1
Mertensia paniculata	0	0	<1	0	0
Maianthemum canadense	2	2	0	0	1
Osmorhiza depauperata	0	0	0	1	0
Petasites palmatus	<1	0	0	0	0
Pyrola asarifolia	<1	0	0	0	0
Rubus pubescens	3	4	2	1	3
Vicia americana	<1	0	0	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	4	1	<1		3
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Eurhynchium pulchellum	1	1	0		1

Toposequence: 1
Transect Position: 35m
Plot No.: W

Date: 12-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea glauca					20
Populus tremuloides					25
Shrubs					**%**
Cornus stolonifera					1
Lonicera involucrata					1
Picea glauca					1
Rosa acicularis					5
Shepherdia canadensis					3
Spiraea betulifolia					3
Viburnum edule					10
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Aster conspicuus	2	5	2	10	5
Cornus canadensis	8	7	2	10	7
Epilobium angustifolium	0	1	0	0	0
Fragaria virginiana	<1	2	4	1	2
Lathyrus ochroleucus	<1	0	<1		0
Linnaea borealis	0	1	<1	1	1
Maianthemum canadense	<1	1	1	0	1
Orchis rotundifolia	0	0	3	1	1
Osmorhiza depauperata	0	0	0	<1	0
Rubus pubescens	1	0	3	<1	1
Vicia americana	<1	0	0	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	1	<1	1	2	1
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Eurhynchium pulchellum	1	4	1	2	2

Toposequence: 1
Transect Position: 80m
Plot No.: C

Date: 12-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Betula papyrifera	2
Picea glauca	3
Pinus contorta	3
Populus balsamifera	15
Populus tremuloides	10
Shrubs	**%**
Amelanchier alnifolia	2
Betula papyrifera	1
Lonicera involucrata	2
Picea glauca	1
Ribes oxyacanthoides	<1
Rosa acicularis	2
Salix planifolia	2
Spiraea betulifolia	5
Viburnum edule	3

Forbs	rep. 1%	rep. 2%	rep. 3%	rep. 4%	% Mean
Aralia nudicaulis	3	5	5	5	5
Aster conspicuus	1	4	5	2	3
Cornus canadensis	<1	4	0	0	1
Galium triflorum	3	0	<1	1	1
Fragaria virginiana	<1	<1	0	0	0
Galium boreale	<1	0	1	0	0
Liliaceae	0	0	<1	2	1
Linnaea borealis	0	0	<1	0	0
Rubus pubescens	1	1	0	0	1
Vicia americana	0	0	0	1	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**% Mean**
Poaceae	40	20	20	20	25
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**% Mean**
Eurhynchium pulchellum	1	5	2	1	2

Toposequence: 1
Transect Position: 100m
Plot No.: C

Date: 12-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Picea glauca	3
Populus balsamifera	2
Populus tremuloides	10
Shrubs	**%**
Amelanchier alnifolia	1
Betula papyrifera	1
Cornus stolonifera	5
Rosa acicularis	3
Salix spp.	1
Shepherdia canadensis	3
Spiraea betulifolia	2
Viburnum edule	2

Forbs	rep. 1%	rep. 2%	rep. 3%	rep. 4%	Mean %
Aralia nudicaulis	3	2	1	2	2
Aster conspicuus	3	0	0	0	1
Cornus canadensis	1	1	1	0	1
Disporum trachycarpum	1	0	0	0	0
Epilobium angustifolium	1	0	1	<1	1
Fragaria virginiana	1	3	<1	1	2
Galium triflorum	0	0	1	0	0
Lathyrus ochroleucus	1	<1	0	0	0
Liliaceae	0	0	2	1	1
Galium boreale	0	7	0	2	2
Mertensia paniculata	0	<1	0	0	0
Pyrola asarifolia	3	0	0	<1	1
Pyrola secunda	0	0	0	1	0
Rubus pubescens	1	4	<1	0	2
Vicia americana	0	0	1	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	5	8	3	4	5
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Eurhynchium pulchellum	1	3	1	2	2

Toposequence: 1
Transect Position: 120m
Plot No.: C
Date: 12-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Picea glauca	2
Populus balsamifera	1
Populus tremuloides	10
Shrubs	**%**
Amelanchier alnifolia	1
Betula papyrifera	2
Lonicera involucrata	1
Picea glauca	<1
Populus tremuloides	<1
Rosa acicularis	3
Shepherdia canadensis	3
Spiraea betulifolia	6
Viburnum edule	3

Forbs	rep. 1%	rep. 2%	rep. 3%	rep. 4%	Mean %
Aralia nudicaulis	2	0	0	1	1
Arnica cordifolia	0	5	0	1	2
Aster conspicuus	0	0	4	3	2
Cornus canadensis	1	3	3	5	3
Epilobium angustifolium	1	1	1	3	2
Galium triflorum	0	0	0	<1	0
Lathyrus ochroleucus	0	0	0	1	0
Galium boreale	<1	2	0	1	1
Linnaea borealis	<1	10	5	<1	8
Osmorhiza depauperata	<1	0	0	0	0
Petasites palmatus	0	0	0	<1	0
Pyrola asarifolia	<1	2	4	0	2
Rubus pubescens	3	<1	0	2	2
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	1	1	2	1	1
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Eurhynchium pulchellum	15	5	1	5	7
Tetraphis pellucida	0	0	0	3	1
Thuidium abietinum	0	0	0	30	8
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**

Toposequence: 1
Transect Position: 120m
Plot No.: E
Date: 17-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Betula papyrifera	12
Picea glauca	1
Populus balsamifera	5
Populus tremuloides	15
Shrubs	**%**
Betula papyrifera	1
Cornus stolonifera	3
Lonicera involucrata	4
Picea glauca	2
Ribes oxyacanthoides	<1
Salix spp	1
Shepherdia canadensis	1
Sorbus scopulina	<1
Spiraea betulifolia	5

Forbs	rep. 1%	rep. 2%	rep. 3%	rep. 4%	Mean %
Aralia nudicaulis	0	5	0	2	2
Arnica cordifolia	0	0	0	<1	0
Aster conspicuus	1	3	3	<1	2
Cornus canadensis	2	5	3	4	4
Epilobium angustifolium	4	0	3	0	2
Fragaria virginiana	<1	<1	0	0	0
Lathyrus ochroleucus	<1	0	<1	1	1
Liliaceae	<1	2	<1	0	1
Linnaea borealis	4	1	1	1	2
Petasites palmatus	0	0	1	0	0
Pyrola spp	0	2	<1	0	1
Ribes hudsonianum	0	0	1	0	0
Rubus pubescens	4	0	3	<1	2
Viola spp	0	1	0	<1	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	<1	3	0	3	2
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Mnium spp	0	1	0	0	0
Peltigera neopolydacum	1	1	0	0	1
Pleurozium schreberi	5	5	7	3	5

Toposequence: 1
Transect Position: 120m
Plot No.: W
Date: 17-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Picea glauca	15
Populus tremuloides	6
Shrubs	**%**
Amelanchier alnifolia	2
Cornus stolonifera	0
Ledum groenlandicum	<1
Lonicera involucrata	1
Populus tremuloides	<1
Rosa acicularis	3
Spiraea betulifolia	2
Symphoricarpos albus	<1
Viburnum edule	1

Forbs	rep. 1%	rep. 2%	rep. 3%	rep. 4%	Mean %
Aralia nudicaulis	0	5	1	5	3
Arnica cordifolia	7	0	3	3	3
Cornus canadensis	7	5	5	<1	6
Equisetum sylvaticum	0	0	<1	0	0
Fragaria virginiana	<1	1	0	<1	1
Maianthemum canadense	0	1	1	0	1
Lathyrus ochroleucus	<1	0	0	<1	0
Liliaceae	0	0	1	1	1
Linnaea borealis	2	3	2	25	8
Petasites palmatus	2	<1	0	0	1
Rubus pubescens	1	0	0	1	1
Vaccinium angustifolium	<1	<1	2	0	1
Vaccinium caespitosum	<1	<1	0	0	0
Vaccinium myrtiloides	0	0	2	0	1
Viola spp	<1	1	1	<1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	2	2	<1	<1	2
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	10	1	20	<1	10
Peltigera aphthose	1	0	0	0	0
Ptilium crista-castrensis	0	0	25	0	6
Pleurozium schreberi	25	10	15	0	13

Toposequence: 1
Transect Position: 150m
Plot No: C

Date: 12-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Picea glauca	10
Populus tremuloides	8
Shrubs	**%**
Alnus crispa	1
Cornus stolonifera	2
Lonicera involucrata	1
Picea glauca	1
Rosa acicularis	1
Shepherdia canadensis	1
Sorbus scopulina	1
Spirea betulifolia	2
Viburnum edule	1

Forbs	rep. 1%	rep. 2%	rep. 3%	rep. 4%	Mean %
Aralia nudicaulis	0	0	0	2	1
Arnica cordifolia	1	2	2	2	2
Cornus canadensis	10	5	5	2	6
Equisetum sylvaticum	1	<1	1	1	1
Fragaria virginiana	0	<1	<1	<1	0
Galium trifiorum	<1	1	<1	0	1
Liliaceae	0	0	<1	0	0
Linnaea borealis	3	3	5	2	3
Galium boreale	0	2	0	1	1
Petasites palmatus	1	0	2	3	2
Pyrola asarifolia	1	1	1	0	1
Pyrola virens	1	0	0	0	0
Rubus pubescens	1	0	2	<1	1
Vaccinium angustifolium	5	<1	0	0	2
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	<1	1	1	0	1
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	40	15	15	1	18
Tetraphis pellucida	0	2	3	0	1
Thuidium abietinum	0	0	0	5	1
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Peltigera canina	1	2	0	1	1

Toposequence: 1
Transect Position: 150m
Plot No: E

Date: 17-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Picea glauca	15
Populus balsamifera	1
Populus tremuloides	18
Shrubs	**%**
Alnus crispa	4
Amelanchier alnifolia	<1
Cornus stolonifera	1
Lonicera involucrata	<1
Rosa acicularis	3
Shepherdia canadensis	2
Spirea betulifolia	5
Viburnum edule	5

Forbs	rep. 1%	rep. 2%	rep. 3%	rep. 4%	Mean %
Aralia nudicaulis	3	6	7	3	5
Arnica cordifolia	4	2	1	1	2
Goodyera repens	0	0	1	0	0
Cornus canadensis	4	8	7	7	7
Epilobium angustifolium	<1	1	1	0	1
Fragaria virginiana	1	<1	<1	<1	1
Galium boreale	<1	0	<1	<1	0
Lathyrus ochroleucus	2	0	0	0	1
Liliaceae	0	<1	1	<1	1
Linnaea borealis	2	1	1	4	2
Maianthemum canadensis	0	0	0	<1	0
Petasites palmatus	6	3	3	1	3
Pyrola spp	0	2	0	0	1
Rubus parviflorus	7	0	0	0	2
Rubus pubescens	<1	3	2	3	3
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	<1	2	1	1	1
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Ceratodon purpureus	1	0	0	0	0
Hylocomium splendens	15	6	20	30	18
Minum spp	23	0	25	0	12
Ptilium crista-castrensis	1	4	5	25	9
Pleurozium schreberi	5	10	10	10	9
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Peltigera aphthosa	0	<1	0	0	0
Peltigera neopolydactyla	1	0	0	0	0

Toposequence: 1
Transect Position: 150m
Plot No: W

Date: 17-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Picea glauca	21
Populus tremuloides	8
Shrubs	**%**
Amelanchier alnifolia	<1
Ledum groenlandicum	<1
Lonicera involucrata	2
Rosa acicularis	1
Shepherdia canadensis	3
Spirea betulifolia	<1
Symphoricarpos albus	<1
Viburnum edule	<1

Forbs	rep. 1%	rep. 2%	rep. 3%	rep. 4%	Mean %
Arnica cordifolia	4	3	2	<1	3
Cornus canadensis	1	7	6	8	6
Epilobium angustifolium	0	1	0	0	0
Equisetum sylvaticum	1	0	<1	<1	1
Fragaria virginiana	2	0	<1	2	1
Lathyrus ochroleucus	0	1	2	1	1
Maianthemum canadense	1	0	<1	0	0
Linnaea borealis	3	3	1	7	4
Petasites palmatus	3	2	2	6	3
Rubus pubescens	0	2	<1	<1	1
Vaccinium angustifolium	0	2	3	0	1
Vaccinium caespitosum	1	2	0	1	1
Vaccinium myrtiloides	1	0	0	<1	0
Vaccinium vitis-idaea	0	0	2	1	1
Viola spp	<1	0	1		1
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	<1	<1	<1	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	30	45	50	10	34
Ptilium crista-castrensis	0	0	10	0	3
Pleurozium schreberi	0	30	30	0	15
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**

Toposequence: 1
Transect Position: 180m
Plot No.: C

Date: 13-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees				%	
Picea glauca				20	
Populus tremuloides				5	
Shrubs				**%**	
Lonicera involucrata				2	
Rosa acicularis				2	
Shepherdia canadensis				1	
Viburnum edule				1	
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Arnica cordifolia	<1	<1	0	1	1
Cornus canadensis	5	3	2	2	3
Equisetum sylvaticum	<1	<1	0	0	0
Fragaria virginiana	1	<1	1	1	1
Galium boreale	0	0	0	<1	0
Galium triflorum	<1	<1	0	0	0
Lathyrus ochroleucus	1	<1	0	0	0
Linnaea borealis	10	2	3	2	4
Petasites palmatus	1	3	1	1	2
Rubus pubescens	1	<1	0	1	1
Viola orbiculata	1	0	0	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	<1	0	0	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Mnesia triquetra	0	<1	0	0	0
Ptilium crista-castrensis	30	40	0	5	19
Pleurozium schreberi	20	25	20	5	18
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Peltigera aphthosa	0	0	2	0	1

Toposequence: 1
Transect Position: 200m
Plot No.: C

Date: 13-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea glauca					15
Populus tremuloides					5
Shrubs					**%**
Ledum groenlendicum					<1
Lonicera involucrata					1
Picea glauca					<1
Rosa acicularis					1
Shepherdia canadensis					1
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Arnica cordifolia	0	0	0	2	1
Cornus canadensis	2	3	2	5	3
Fragaria virginiana	0	<1	1	<1	1
Lathyrus ochroleucus	1	<1	0	1	1
Linnaea borealis	1	<1	<1	2	2
Mitella nuda	0	0	3	3	2
Petasites palmatus	1	3	1	1	2
Ribes pubescens	0	<1	0	0	0
Galium boreale	1	60	60	40	45
Galium triflorum	0	<1	0	<1	0
Vaccinium angustifolium	0	2	0	0	1
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Dicranum spp.	3	0	0	0	1
Pleurozium schreberi	1	0	3	40	11
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Peltigera aphthosa	0	0	0	3	1

Toposequence: 1
Transect Position: 280m
Plot No: C

Date: 13-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
				%	
Picea glauca				20	
Salix spp				15	
Shrubs				**%**	
Ledum groenlandicum				<1	
Lonicera involucrata				6	
Ribes hudsonianum				1	
Salix spp				6	
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
1	3	0	0	1	1
2	1	0	0	0	0
Arnica cordifolia	3	0	0	0	1
Cornus canadensis	0	2	1	1	1
Equisetum sylvaticum	2	1	3	1	2
Fragaria virginiana	1	<1	<1	0	1
Galium triflorum	<1	<1	<1	0	0
Liliaceae	0	1	<1	<1	1
Linnaea borealis	0	0	2	0	1
Mertensia paniculata	0	2	0	0	1
Mitella nuda	5	2	3	1	3
Galium triflorum	2	0	2	1	1
Rubus pubescens	2	1	0	0	1
Viola orbiculata	0	1	<1	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	<1	2	4		3
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
3	20	0	10		10
Hylocomium splendens	2	0	0		1
Sphagnum 4	0	10			
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**

Toposequence: 1
Transect Position: 280m
Plot No: E

Date: 17-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
				%	
Larix laricina				3	
Picea glauca				3	
Picea mariana				4	
Shrubs				**%**	
Betula pumila				1	
Ledum groenlandicum				35	
Lonicera involucrata				<1	
Picea mariana				4	
Rosa acicularis				2	
Salix spp				11	
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Cornus canadensis	2	6	6	<1	5
Epilobium angustifolium	0	0	0	4	1
Gaultheria hispidula	2	0	4	1	2
Linnaea borealis	0	<1	0	0	0
Mitella nuda	1	0	0	2	1
Rubus pubescens	<1	0	1	1	1
Vaccinium angustifolium	<1	1	<1	0	1
Vaccinium caespitosum	0	<1	0	0	0
Vaccinium vitis-idaea	0	1	0	0	0
Viola spp	0	0	<1	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Ceratodon purpureus	6	1	1	1	2
Hylocomium splendens	0	0	0	8	2
Ptilium crista-castrensis	0	0	10	10	5
Pleurozium schreberi	20	32	75	10	34
Sphagnum spp	50	62	7	60	45
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Cladia mitis	<1	0	1	0	0
Peltigera aphthosa	1	0	1	2	1

Toposequence: 1
Transect Position: 280m
Plot No: W

Date: 17-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
				%	
Shrubs				**%**	
Alnus rugosa				1	
Betula papyrifera				<1	
Lonicera involucrata				1	
Picea glauca				1	
Ribes oxyacanthoides				<1	
Ribes hudsonianum				1	
Salix spp				8	
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
1	0	0	0	1	0
Arnica cordifolia	0	0	<1	0	0
Cornus canadensis	3	2	3	0	2
Equisetum pratense	<1	0	0	0	0
Galium boreale	0	<1	<1	0	0
Galium triflorum	1	<1	1	0	1
Liliaceae	0	1	1	1	1
Linnaea borealis	0	0	1	0	0
Maianthemum canadense	1	0	0	0	0
Rubus pubescens	<1	2	1	1	1
Viola spp	0	0	1	1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	40	20	40	30	33
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
1	0	6	0	0	2
Ceratodon purpureus	0	0	10	3	3
Mnium spp	1	5	2	10	5
Pleurozium schreberi	1	0	0	3	1
Sphagnum spp	0	0	5	0	1
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**

Toposequence: 2
Transect Position: 12.5m
Plot No: C

Date: 14-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Populus balsamifera					1
Picea glauca					5
Populus tremuloides					8
Shrubs					**%**
Alnus crispa					5
Amelanchier alnifolia					<1
Ledum groenlandicum					5
Picea glauca					1
Populus tremuloides					<1
Rosa acicularis					1
Spiraea betulifolia					2
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
1	1	1	<1	0	1
Cornus canadensis	4	5	1	10	5
Epilobium angustifolium	1	<1	0	1	1
Liliaceae	0	0	0	1	0
Linnaea borealis	1	4	<1	2	2
Lycopodium annotinum	0	4	40	0	11
Lycopodium clavatum	1	0	0	<1	0
Galium triflorum	0	0	0	<1	0
Lycopodium obscurum	15	0	0	8	6
Petasites palmatus	0	0	<1	1	0
Galium boreale	2	1	<1	1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	1	0	0	0	0
Pleurozium schreberi	15	12	0	3	8
Ptilium crista-castrensis	2	5	0	2	2

Toposequence: 2
Transect Position: 12.5
Plot No: NE

Date: 17-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Populus tremuloides					19
Picea glauca					29
Shrubs					**%**
Alnus crispa					4
Ledum groenlandicum					2
Lonicera involucrata					<1
Picea mariana					3
Shepherdia canadensis					<1
Sorbus scopulina					<1
Spiraea betulifolia					2
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Cornus canadensis	15	5	8	5	8
Epilobium angustifolium	<1	2	<1	0	1
Equisetum sylvaticum	0	<1	0	0	0
Liliaceae	0	2	3	1	2
Linnaea borealis	<1	1	2	3	2
Lycopodium annotinum	6	7	11	3	7
Lycopodium complanatum	7	0	3	1	3
Lycopodium obscurum	0	<1	0	0	0
Mitella nuda	3	4	0	3	3
Petasites palmatus	1	2	0	2	1
Rubus pubescens	0	2	0	0	1
Vaccinium angustifolium	<1	<1	<1	<1	0
Vaccinium myrtiloides	2	1	0	<1	1
Vaccinium vitis-idaea	0	<1	4	0	1
Viola spp	<1	0	0	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	0	0	0	10	3
Ptilium crista-castrensis	2	0	10	2	4
Pleurozium schreberi	2	50	50	18	30
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**

Toposequence: 2
Transect Position: 12.5
Plot No: SW

Date: 17-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea glauca					12
Picea marina					12
Populus tremuloides					15
Shrubs					**%**
Alnus crispa					4
Amelanchier alnifolia					<1
Ledum groenlandicum					1
Lonicera involucrata					<1
Picea mariana					2
Spiraea betulifolia					3
Forbs	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Cornus canadensis	11	9	6	7	8
Epilobium angustifolium	0	0	2	0	1
Linnaea borealis	5	1	1	8	4
Lycopodium annotinum	1	0	0	0	0
Lycopodium complanatum	<1	0	1	0	0
Lycopodium obscurum	0	0	0	5	1
Maianthemum canadense	0	0	0	3	1
Petasites palmatus	3	0	2	0	1
Vaccinium angustifolium	<1	<1	1	<1	1
Vaccinium myrtiloides	<1	<1	1	<1	1
Vaccinium vitis-idaea	1	1	1	2	1
Grasses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Poaceae	0	0	0	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	30	35	70	35	43
Ptilium crista-castrensis	20	20	5	11	14
Pleurozium schreberi	45	35	25	40	36
Lichen	**rep. 1%**	**rep. 2%**	**rep. 3%**	**rep. 4%**	**Mean %**
Peltigera neopolydactyla	0	2	0		1

Toposequence: 2
Transect Position: 50m
Plot No.: C

Date: 14-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Picea glauca	20
Picea mariana	2
Populus tremuloides	12

Shrubs	%
Alnus crispa	<1
Ledum groenlandicum	1
Lonicera involucrata	2
Picea mariana	2
Rosa acicularis	3
Shepherdia canadensis	1
Spiraea betulifolia	2

Forbs	rep. 1%	rep. 2%	rep.3%	rep. 4%	Mean %
1	<1	0	<	1	1
Arnica cordifolia	<1	0	0	0	0
Cornus canadensis	3	7	4	4	5
Equisetum pratense	0	0	0	<1	0
Lathyrus ochroleucus	0	0	1	<1	0
Linnaea borealis	1	3	3	2	2
Lycopodium complanatum	2	3	0	0	1
Galium triflorum	0	0	0	1	0
Petasites palmatus	<1	0	0	1	0
Pyrola spp.	0	3	0	1	1
Galium boreale	1	2	1	2	2
Viola spp.	1	0	0	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	<1	1	0	0	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	5	2	25	5	9
Peltigera aphthosa	0	<1	1	0	0
Pleurozium schreberi	70	2	45	30	37
Ptilium crista-castrensis	15	3	5	5	7

Toposequence: 2
Transect Position: 65m
Plot No: C
Date: 14-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Abies balsamea					4
Picea glauca					25
Picea mariana					4
Populus balsamifera					1
Populus tremuloides					10
Shrubs					**%**
Alnus crispa					2
Amelanchier alnifolia					<1
Ledum groenlandicum					2
Lonicera involucrata					<1
Picea glauca					1
Picea mariana					1
Rosa acicularis					1
Shepherdia canadensis					1
Spiraea betulifolia					2
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
1	0	1	1	1	1
2	0	0	0	1	0
Cornus canadensis	2	3	10	10	6
Galium triflorum	0	0	<1	0	0
Lathyrus ochroleucus	1	1	1	0	1
Liliaceae	0	0	0	<1	0
Galium boreale	3	0	0	1	1
Lycopodium complanatum	0	1	0	0	0
Maianthemum canadense	0	0	1	2	1
Petasites palmatus	0	0	0	1	0
Pyrola spp	0	0	<1	0	0
Vaccinium angustifolium	1	1	1	1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	5	<1	<1	2	4
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Dicranum spp	0	3	0		1
Hylocomium splendens	10	20	35	15	20
Pleurozium schreberi	20	40	35	10	28
Ptilium crista-castrensis	30	25	10		22

Toposequence: 2
Transect Position: 65m
Plot No: NE
Date: 18-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea glauca					8
Picea mariana					5
Populus balsamifera					1
Populus tremuloides					12
Shrubs					**%**
Alnus crispa					1
Alnus rugosa					1
Amelanchier alnifolia					<1
Betula papyrifera					1
Ledum groenlandicum					1
Lonicera involucrata					2
Rosa acicularis					2
Salix spp					<1
Spiraea betulifolia					3
Shepherdia canadensis					2
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Cornus canadensis	2	3	5	8	5
Epilobium angustifolium	1	2	4	0	2
Equisetum pratense	0	<1	<1	0	0
Lathyrus ochroleucus	0	1	<1	<1	1
Liliaceae	<1	0	0	<1	0
Linnaea borealis	5	6	3	<1	5
Lycopodium complanatum	1	0	0	0	0
Petasites palmatus	0	0	0	<1	0
Pyrola spp	1	<1	0	0	0
Rubus pubescens	0	<1	0	0	0
Vaccinium cespitosum	1	0	<1	<1	1
Vaccinium myrtiloides	2	1	1	1	1
Vaccinium vitis-idaea	2	0	0	2	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	<1	<1	0	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Dicranum spp.	25	0	1	0	7
Hylocomium splendens	5	0	5	0	3
Peltigera aphthosa	0	0	0	<1	0
Pleurozium schreberi	5	1	2	4	3
Ptilium crista-castrensis	5	0	15	0	5

Toposequence: 2
Transect Position: 65m
Plot No: SW
Date: 18-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea glauca					12
Picea mariana					13
Populus tremuloides					14
Shrubs					**%**
Alnus crispa					4
Amelanchier alnifolia					<1
Betula papyrifera					1
Ledum groenlandicum					4
Lonicera involucrata					<1
Rosa acicularis					<1
Salix spp					<1
Shepherdia canadensis					1
Spiraea betulifolia					<1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Cornus canadensis	6	4	5	6	5
Epilobium angustifolium	0	2	0	1	1
Fragaria virginiana	0	<1	0	0	0
Linnaea borealis	<1	<1	<1	<1	0
Maianthemum canadense	<1	0	0	0	0
Vaccinium angustifolium	<1	<1	<1	0	0
Vaccinium cespitosum	0	<1	0	0	0
Vaccinium myrtiloides	0	1	2	<1	1
Vaccinium vitis-idaea	<1	1	<1	<1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	<1	<1	0	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	15	15	10	40	20
Pleurozium schreberi	35	20	20	2	19
Ptilium crista-castrensis	50	5	30	8	23

Toposequence: 2
Transect Position: 85m
Plot No.: C

Date: 14-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees	%
Betula papyrifera	6
Picea glauca	17
Picea mariana	11
Populus balsamifera	10
Populus tremuloides	0
Shrubs	**%**
Amelanchier alnifolia	1
Betula papyrifera	1
Ledum groenlandicum	<1
Lonicera involucrata	2
Picea mariana	2
Ribes oxyacanthoides	<1
Rosa acicularis	2
Salix spp.	1
Shepherdia canadensis	1

Forbs	rep. 1%	rep. 2%	rep.3%	rep. 4%	Mean %
1	<1	1	<1	<1	1
Arnica cordifolia	2	3	<1	1	2
Cornus canadensis	3	3	4	8	5
Galium triflorum	2	0	0	1	1
Equisetum pratense	1	1	<1	1	1
Fragaria virginiana	1	1	1	0	1
Galium boreale	1	0	<1	<1	1
Geum rivale	0	0	4	0	1
Liliaceae	0	0	<1	1	0
Linnaea borealis	0	1	0	0	0
Mitella nuda	2	2	1	2	2
Petasites palmatus	1	3	0	2	2
Rubus pubescens	0	2	3	3	2
Vaccinium angustifolium	1	1	<1	0	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	15	30	0	0	11
Pleurozium schreberi	20	40	40	4	26
Ptilium criste-castrensis	0	20	45	1	17

Toposequence: 2
Transect Position: 110m
Plot No: C

Date: 14-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Betula papyrifera					2
Larix laricina					2
Picea glauca					10
Picea mariana					30
Populus balsamifera					5
Shrubs					**%**
Ledum groenlandicum					3
Lonicera involucrata					1
Picea mariana					2
Rosa acicularis					<1
Salix spp					1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
1	<1	<1	<1	1	1
Arnica cordifolia	2	0	0	2	1
Cornus canadensis	7	8	4	9	7
Equisetum pratense	<1	1	1	1	1
Equisetum sylvaticum	<1	0	1	0	0
Fragaria virginiana	<1	0	1	<1	1
Galium boreale	<1	<	0	0	0
Galium triflorum	0	2	5	0	2
Linnaea borealis	1	<1	<1	1	1
Mitella nuda	3	1	<1	3	2
Galium boreale	0	0	3	0	1
Vaccinium angustifolium	0	0	8	0	2
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	40	35	0	10	21
Pleurozium schreberi	50	40	45	40	44
Polytrichum commune	0	0	10	0	3
Ptilium crista-castrensis	5	10	30	10	14
Sphagnum spp	0	12	10	0	6

Toposequence: 2
Transect Position: 110m
Plot No: NE

Date: 18-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea glauca					5
Picea mariana					40
Shrubs					**%**
Ledum groenlandicum					3
Lonicera involucrata					<1
Picea mariana					1
Rosa acicularis					<1
Shepherdia canadensis					<1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Cornus canadensis	1	0	0	0	0
Equisetum pratense	<1	2	1	<1	2
Equisetum sylvaticum	<1	0	<1	0	0
Gaultheria hispidula	0	1	0	0	0
Liliaceae	0	0	2	0	1
Linnaea borealis	0	1	2	0	1
Mitella nuda	2	2	3	<1	2
Petasites palmatus	0	1	0	0	0
Vaccinium vitis-idaea	1	1	1	1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	1	<1	1	<1	1
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	60	35	25	25	36
Peltigera aphthosa	1	1	0	0	1
Peltigera neopolydactyla	0	0	2	0	1
Pleurozium schreberi	40	65	45	25	44
Sphagnum spp	0	0	30	0	8

Toposequence: 2
Transect Position: 110m
Plot No: SW

Date: 18-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Picea mariana					35
Populus tremuloides					5
Shrubs					**%**
Ledum groenlandicum					3
Picea mariana					2
Rosa acicularis					<1
Shepherdia canadensis					<1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Arnica cordifolia	0	0	0	<1	0
Cornus canadensis	6	3	6	5	5
Epilobium angustifolium	1	0	0	0	0
Equisetum pratense	0	0	0	<1	0
Equisetum sylvaticum	0	0	0	<1	0
Fragaria virginiana	0	0	0	<1	0
Galium boreale	0	0	0	<1	0
Linnaea borealis	<1	1	<1	1	1
Mitella nuda	0	0	0	<1	0
Petasites palmatus	1	0	<1	2	1
Maianthemum canadense	0	0	<1	0	0
Vaccinium angustifolium	1	<1	<1	<1	1
Vaccinium cespitosum	0	0	0	<1	0
Vaccinium myrtiloides	<1	1	0	<1	1
Vaccinium vitis-idaea	<1	<1	<1	<1	0
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	2	1	0	0	1
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Dicranum spp	1	0	0	0	0
Hylocomium splendens	39	60	25	15	35
Peltigera aphthosa	0	0	7	0	2
Pleurozium schreberi	30	15	23	20	22
Ptilium crista-castrensis	30	10	35	60	34

Toposequence: 3
Transect Position: 10m
Plot No.: C

Date: 16-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
					%
Betula papyrifera					12
Picea mariana					25
Pinus contorta					4
Populus balsamifera					3
Populus tremuloides					4
Shrubs					**%**
Amelanchier alnifolia					<1
Betula papyrifera					2
Lonicera involucrata					4
Picea mariana					2
Rosa acicularis					2
Salix spp					1
Shepherdia canadensis					1
Viburnum edule					1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Cornus canadensis	5	4	7	2	5
Epilobium angustifolium	0	1	1	0	1
Fragaria virginiana	<1	0	1	<1	1
Galium triflorum	0	0	<1	0	0
Liliaceae	0	0	0	<1	0
Linnaea borealis	2	1	2	1	2
Galium boreale	0	1	5	0	2
Petasites palmatus	1	1	3	0	1
Rubus pubescens	<1	0	0	2	1
Vaccinium angustifolium	1	1	<1	<1	1
Vaccinium cespitosum	1	1	1	0	1
Vaccinium myrtiloides	0	0	2	1	1
Viola spp	0	0	<1	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	0	<1	<1	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Ceratodon purpureus	0	0	1	0	0
Hylocomium splendens	40	30	40	35	36
Peltigera aphthosa	0	0	1	0	0
Pleurozium schreberi	50	20	50	50	43
Ptilium crista-castrensis	0	20	0	0	5

Toposequence: 3
Transect Position: 10m
Plot No.: E

Date: 26-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
					%
Betula papyrifera					18
Picea mariana					13
Picea glauca					4
Populus balsamifera					4
Populus tremuloides					13
Shrubs					**%**
Betula papyrifera					4
Lonicera involucrata					1
Picea mariana					2
Rosa acicularis					1
Shepherdia canadensis					<1
Viburnum edule					1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Aralia nudicaulis	0	2	7	2	3
Arnica cordifolia	2	<1	1	<1	2
Cornus canadensis	5	6	4	3	5
Epilobium angustifolium	0	0	1	0	0
Fragaria virginiana	<1	<1	1	0	1
Liliaceae	<1	0	<1	<1	0
Linnaea borealis	4	2	2	2	3
Petasites palmatus	1	<1	1	<1	1
Pyrola spp	<1	0	2	4	2
Rubus pubescens	<1	0	0	0	0
Vaccinium cespitosum	<1	0	<1	0	0
Vaccinium myrtiloides	2	2	<1	<1	2
Vaccinium vitis-idaea	0	0	<1	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	0	0	0	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	2	1	12	1	4
Pleurozium schreberi	18	30	3	8	15
Ptilium crista-castrensis	0	25	12	1	10

Toposequence: 3
Transect Position: 10m
Plot No.: W

Date: 26-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
					%
Betula papyrifera					6
Picea mariana					23
Picea glauca					6
Shrubs					**%**
Betula papyrifera					4
Lonicera involucrata					2
Ledum groenlandicum					1
Picea glauca					<1
Picea mariana					2
Rosa acicularis					1
Salix spp					1
Shepherdia canadensis					<1
Viburnum edule					<1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Aralia nudicaulis	0	0	0	4	1
Arnica cordifolia	0	1	<1	0	0
Cornus canadensis	1	9	0	4	4
Maianthemum canadense	2	1	1	0	1
Equisetum sylvaticum	1	<1	0	0	0
Fragaria virginiana	1	1	<1	<1	1
Liliaceae	1	<1	0	<1	1
Linnaea borealis	<1	1	<1	1	1
Petasites palmatus	2	1	1	1	1
Rubus pubescens	0	0	0	<1	0
Vaccinium angustifolium	0	<1	0	2	1
Vaccinium cespitosum	<1	<1	1	<1	1
Vaccinium myrtiloides	3	<1	10	5	6
Vaccinium vitis-idaea	2	1	0	0	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	0	<1	1	<1	1
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	40	25	30	40	34
Peltigera aphthosa	1	1	9	0	3
Pleurozium schreberi	60	40	50	60	53

Toposequence: 3
Transect Position: 25m
Plot No.: C

Date: 16-Aug-98
Sampler: Todd an Andrea
Recorder: Todd an Andrea

Trees	%
Betula papyrifera	9
Picea glauca	2
Picea mariana	18
Populus balsamifera	1
Populus tremuloides	20
Shrubs	**%**
Alnus rugosa	<1
Amelanchier alnifolia	<1
Betula papyrifera	1
Ledum groenlandicum	2
Lonicera involucrata	3
Picea mariana	2
Salix spp.	1
Shepherdia canadensis	1
Viburnum edule	3

Forbs	rep. 1%	rep. 2%	rep.3%	rep. 4%	Mean %
Arnica cordifolia	<1	1	0	0	0
Aster conspicuus	0	3	0	0	1
Galium triflorum	3	8	4	4	5
Epilobium angustifolium	0	0	0	2	1
Equisetum sylvaticum	0	<1	0	0	0
Galium boreale	1	<1	0	0	0
Lathyrus ochroleucus	<1	0	0	<1	0
Lilieceae	2	1	1	<1	1
Linneea borealis	2	5	3	0	3
Lycopodium annotinum	0	<1	2	0	1
Lycopodium complanatum	0	0	0	1	0
Petasites palmatus	<1	<1	<1	0	0
Rubus pubescens	2	<1	0	2	1
Vaccinium angustifolium	<1	1	1	<1	1
Vaccinium caespitosum	<1	1	0	0	0
Vaccinium myrtiloides	1	3	1	1	2
Vaccinium vitis-idaea	<1	0	1	1	1
Viola spp.	1	<1	2	0	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	0	0	0	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
1	0	0	1	0	0
Cladine spp.	0	0	<1	0	0
Dicranum spp.	0	0	2	0	1
Hylocomium splendens	30	10	20	10	18
Pleurozium schreberi	40	5	30	57	33
Ptilium crista-castrensis	0	0	3	3	2

Toposequence: 3
Transect Position: 75
Plot No.: C

Date: 16-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Alnus rugosa					3
Betula papyrifera					7
Picea mariana					7
Populus tremuloides					20
Shrubs					**%**
Alnus rugosa					2
Betula papyrifera					<1
Ledum groenlandicum					2
Lonicera involucrata					2
Rosa acicularis					3
Shepherdia canadensis					<1
Viburnum edule					3
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Arnica cordifolia	<1	2	<1	3	3
Aster conspicuus	<1	1	0	0	0
Cornus canadensis	5	3	2	2	3
Epilobium angustifolium	1	0	1	3	1
Equisetum pratense	0	0	<1	0	0
Galium triflorum	<1	0	0	<1	0
Fragaria virginiana	<1	0	<1	<1	0
Lathyrus ochroleucus	<1	<1	0	0	0
Galium boreale	2	2	2	3	2
Mitella nuda	1	2	3	0	2
Petasites palmatus	1	0	1	0	1
Rubus pubescens	1	3	<1	3	2
Vaccinium angustifolium	1	1	1	<1	1
Vaccinium cespitosum	<1	<1	0	0	0
Vaccinium myrtiloides	1	2	5	<1	3
Vaccinium vitis-idaea	0	0	0	1	0
Viola spp	3	0	2	<1	2
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	<1	<1	<1	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Ceratodon purpureus	3	0	0		1
Hylocomium splendens	2	1	10		4
Mnium spp	2	0	0		1
Pleurozium schreberi	5	7	20		11

Toposequence: 3
Transect Position: 75m
Plot No.: E

Date: 28-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Betula papyrifera					6
Picea glauca					6
Picea mariana					12
Populus tremuloides					21
Shrubs					**%**
Alnus crispa					1
Betula papyrifera					2
Ledum groenlandicum					4
Lonicera involucrata					1
Picea mariana					2
Shepherdia canadensis					2
Viburnum edule					0
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Cornus canadensis	9	6	11	18	11
Epilobium angustifolium	0	0	0	<1	0
Equisetum sylvaticum	0	0	0	<1	0
Lathyrus ochroleucus	<1	0	1	<	1
Liliaceae	0	0	<1	0	0
Linnaea borealis	5	2	1	1	2
Lycopodium complanatum	1	3	0	0	1
Petasites palmatus	<1	0	<1	<1	0
Vaccinium caespitosum	0	0	0	<1	0
Vaccinium myrtiloides	3	2	3	2	3
Vaccinium vitis-idaea	1	0	1	1	1
Viola spp	<1	0	0	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	0	0	<1	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	27	10	60	3	25
Peltigera aphthosa	0	2	0		1
Pleurozium schreberi	60	15	20	50	36
Ptilium crista-castrensis	3	5	1	40	12

Toposequence: 3
Transect Position: 75m
Plot No.: W

Date: 28-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					%
Betula papyrifera					4
Picea glauca					1
Picea mariana					17
Populus balsamifera					2
Populus tremuloides					16
Shrubs					**%**
Alnus rugosa					2
Betula papyrifera					1
Ledum groenlandicum					2
Lonicera involucrata					4
Picea mariana					7
Salix spp					1
Shepherdia canadensis					<1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Arnica cordifolia	1	<1	<1	0	1
Cornus canadensis	1	15	14	6	9
Epilobium angustifolium	0	0	0	<1	0
Maianthemum canadense	0	0	<1	0	0
Fragaria virginiana	0	<1	<1	<1	0
Linnaea borealis	1	2	0	<1	1
Lycopodium complanatum	0	0	0	<1	0
Mitella nuda	<1	0	1	<1	1
Petasites palmatus	2	<1	2	1	2
Pyrola spp	1	0	0	0	0
Rubus pubescens	1	0	<1	0	0
Vaccinium angustifolium	0	<1	<1	0	0
Vaccinium cespitosum	0	<1	<1	0	0
Vaccinium myrtiloides	<1	<1	1	0	1
Vaccinium vitis-idaea	<1	2	<1	<1	2
Viola spp	0	<1	<1	<1	0
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	0	<1	0	0	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	0	40	12	30	21
Mnium spp	0	2	<1	0	1
Peltigera aphthosa	0	0	0	3	1
Pleurozium schreberi	9	40	50	40	35
Ptilium crista-castrensis	0	10	8	0	5

Toposequence: 3
Transect Position: 125m
Plot No.: C

Date: 16-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
					%
Picea mariana					22
Populus tremuloides					2
Shrubs					**%**
Betula papyrifera					<1
Ledum groenlandicum					3
Lonicera involucrata					1
Picea mariana					5
Rosa acicularis					1
Salix spp					1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Arnica cordifolia	1	0	0	0	0
Cornus canadensis	6	7	2	2	4
Equisetum pratense	<1	1	0	<1	1
Fragaria virginiana	<1	<1	0	0	0
Liliaceae	0	<1	0	0	0
Linnaea borealis	2	2	1	3	2
Lycopodium complanatum	0	1	1	0	1
Vaccinium angustifolium	1	0	<1	0	0
Galium triflorum	<1	<1	<1	<1	0
Vaccinium myrtiloides	1	0	0	0	0
Vaccinium vitis-idaea	<1	1	0	0	0
Galium borealis	<1	0	0	0	0
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	0	0	<1		0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Ceratodon purpureus	1	1	<1	3	2
Dicranum spp	1	0	15	0	4
Hylocomium splendens	8	5	10	60	21
Pleurozium schreberi	10	34	30	27	25
Ptilium crista-castrensis	80	60	45	5	48

Toposequence: 3
Transect Position: 125m
Plot No.: E

Date: 27-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
					%
Larix laricina					8
Picea mariana					22
Shrubs					**%**
Ledum groenlandicum					4
Lonicera involucrata					2
Picea mariana					8
Ribes oxyacanthoides					<1
Rosa acicularis					2
Salix spp					3
Shepherdia canadensis					<1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Arnica cordifolia	1	0	2	0	1
Cornus canadensis	4	2	2	3	3
Equisetum pratense	4	2	<1	1	2
Equisetum sylvaticum	3	1	0	2	2
Fragaria virginiana	<1	0	<1	0	0
Gaultheria hispidula	0	3	0	0	1
Lathyrus ochroleucus	1	0	<1	<1	1
Linnaea borealis	0	0	1	<1	0
Mitella nuda	0	0	0	<1	0
Petasites palmatus	0	3	0	0	1
Rubus chamaemorus	0	1	0	0	0
Vaccinium myrtiloides	5	0	1	<1	2
Vaccinium vitis-idaea	<1	<1	<1	<1	0
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	0	0	0	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Ceratodon purpureus	2	0	0	0	1
Cladina mitis	<1	0	0	0	0
Hylocomium splendens	37	43	0	60	35
Pleurozium schreberi	60	55	100	40	64
Minum spp	0	1	0	0	0
Sphagnum spp	0	1	0	0	0

Toposequence: 3
Transect Position: 125m
Plot No.: W

Date: 27-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
					%
Picea mariana					34
Pinus contorta					1
Shrubs					**%**
Ledum groenlandicum					3
Lonicera involucrata					2
Picea mariana					15
Rosa acicularis					<1
Salix spp					<1
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Arnica cordifolia	0	1	0	<1	0
Cornus canadensis	3	4	5	7	5
Epilobium angustifolium	1	<1	0	2	1
Equisetum arvense	0	<1	0	0	0
Equisetum pratense	0	0	0	<1	0
Fragaria virginiana	0	1	0	0	0
Linnaea borealis	1	1	<1	1	1
Lycopodium complanatum	0	3	0	0	1
Maianthemum canadense	0	0	0	<1	0
Vaccinium angustifolium	0	0	0	<1	0
Vaccinium myrtiloides	1	<1	2	<1	2
Vaccinium vitis-idaea	<1	1	1	<1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Dicranum spp	1	0	0	0	0
Hylocomium splendens	15	60	5	30	28
Peltigera aphthosa	<1	0	0	0	0
Pleurozium schreberi	58	30	80	65	58
Ptilium crista-castrensis	15	6	10	0	8

Toposequence: 3
Transect Position: 140m
Plot No.: C

Date: 16-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees				%	
Picea mariana				20	
Shrubs				**%**	
Ledum groenlandicum				3	
Lonicera involucrata				<1	
Picea mariana				1	
Salix spp				8	
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Cornus canadensis	0	0	0	1	0
Equisetum pratense	1	<1	1	1	1
Equisetum sylvaticum	1	3	<1	<1	2
Lathyrus ochroleucus	0	0	0	<1	0
Liliaceae	1	0	2	0	1
Linnaea borealis	0	0	0	<1	0
Pelesites palmatus	1	<1	0	0	0
Galium boreale	0	0	0	1	0
Galium triflorum	1	<1	20	<1	11
Rubus chamaemorus	1	5	<1	0	2
Vaccinium angustifolium	0	0	0	<1	0
Vaccinium vitis-idaea	1	1	0	1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	30	5	25	10	18
Pleurozium schreberi	50	50	50	30	45
Ptilium crista-castrensis	20	35	0	20	19
Sphagnum spp.	0	10	25	40	19

Toposequence: 3
Transect Position: 275m
Plot No.: C

Date: 16-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
				%	
Larix laricina				1	
Picea mariana				15	
Shrubs				%	
Betula pumila				1	
Larix laricina				2	
Ledum groenlandicum				25	
Picea mariana				8	
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Equisetum arvense	<1	0	0	0	0
Geum rivale	4	0	0	0	1
Liliaceae	0	2	2	3	2
Linnaea borealis	3	2	0	0	1
Mitella nuda	<1	0	<1	0	0
Oxycoccus microcarpus	0	2	1	1	1
Rubus chamaemorus	0	2	1	6	2
Galium boreale	20	0	0	0	5
Vaccinium vitis-idaea	8	3	2	3	4
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	2	<1	2	2	2
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Ceratodon purpureus	0	6	5	1	3
Cladonia mitis	0	2	0	0	1
Aulacomnium palustre	0	2	0	8	3
Pleurozium schreberi	40	62	20	3	36
Sphagnum spp	40	8	75	45	42

Toposequence: 3
Transect Position: 275m
Plot No.: E

Date: 27-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
				%	
Picea mariana				10	
Shrubs				%	
Betula pumila				2	
Larix laricina				8	
Ledum groenlandicum				5	
Picea mariana				3	
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Galium boreale	<1	0	<1	0	0
Equisetum pratense	0	0	<1	1	0
Liliaceae	1	3	3	2	2
Oxycoccus microcarpus	0	0	1	2	1
Ranunculus lapponicus	<1	0	0	0	0
Rubus chamaemorus	8	2	7	3	5
Vaccinium vitis-idaea	3	0	4	2	2
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	1	3	3	2	2
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	30	0	0	0	8
Pleurozium schreberi	50	0	0	55	26
Ptilium crista-castrensis	5	0	0	0	1
Sphagnum spp	15	100	90	45	63

Toposequence: 3
Transect Position: 275m
Plot No.: W

Date: 27-Aug-98
Sampler: Todd and Andrea
Recorder: Todd and Andrea

Trees					
				%	
Larix laricina				2	
Picea mariana				13	
Shrubs				%	
Betula pumila				1	
Larix laricina				2	
Ledum groenlandicum				25	
Picea mariana				13	
Forbs	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Liliaceae	0	1	1	<1	1
Oxycoccus microcarpus	<1	<1	<1	1	1
Rubus chamaemorus	4	7	1	4	4
Maianthemum canadense	80	95	85	25	71
Vaccinium vitis-idaea	1	<1	1	1	1
Grasses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Poaceae	<1	0	0	<1	0
Mosses	**rep. 1%**	**rep. 2%**	**rep.3%**	**rep. 4%**	**Mean %**
Hylocomium splendens	0	0	10	2	3
Pleurozium schreberi	15	5	5	73	25

APPENDIX VI

Regression of soil texture upon Field Capacity.

This regression model was generated from data collected by Verma (1968). Only data from horizons with <2% organic matter were used to develop these equations, since mineral horizons of Gray Luvisolic soils generally contain low concentrations of soil organic matter.

Reference

Verma, T. R. 1968. Moisture balance in soils of the Edmonton area. Unpubl. Ph. D. dissertation. Univ. of Alberta, Edmonton, Alberta.

The selected model:
FC (%) = Silt(%) + Clay(%)

Multiple R	0.90468
R Square	0.81844
Adjusted R Square	0.81670
Standard Error	4.57731

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	2	19645.14921	9822.57461
Residual	208	4357.95979	20.95173

F = 468.81927 Signif F = 0.0000

---------- Variables in the Equation ----------

Variable	(Coefficient) B	(SE of Coeff.) SE B	Beta	(t-stat) T Sig	(p-value) T
SILT	0.266042	0.021861	0.376421	12.170	0.0000
TOT_CL	0.465932	0.020052	0.718716	23.236	0.0000
(Constant)	1.883405	0.884046	2.130		0.0343

Residuals Statistics

	Min	Max	Mean	Std Dev	N
*PRED	2.6154	42.8811	25.6635	9.6720	211
*RESID	-9.2175	23.3821	0.0000	4.5555	211
*ZPRED	-2.3830	1.7801	0.0000	1.0000	211
*ZRESID	-2.0137	5.1083	0.0000	0.9952	211

Total Cases = 212

APPENDIX VII

Regression of soil texture upon of Permanent Wilting Point.

This regression model was generated from data collected by Verma (1968). Only data from horizons with <2% organic matter were used to develop these equations, since mineral horizons of Gray Luvisolic soils generally contain low concentrations of soil organic matter.

Reference

Verma, T. R. 1968. Moisture balance in soils of the Edmonton area. Unpubl. Ph. D. dissertation. Univ. of Alberta, Edmonton, Alberta.

The selected model:
PWP (%) = Silt(%) + Clay(%)

Multiple R	0.94597
R Square	0.89487
Adjusted R Square	0.89386
Standard Error	1.86281

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	2	6143.58157	3071.79079
Residual	208	721.77625	3.47008

F = 885.22238 Signif F = 0.0000

---------- Variables in the Equation ----------

Variable	(Coefficient) B	(SE of Coeff.) SE B	Beta	(t-stat) T Sig	(p-value) T
SILT	0.067493	0.008897	0.178560	7.586	0.0000
TOT_CL	0.304273	0.008161	0.877606	37.286	0.0000
(Constant)	0.459615	0.359778		1.277	0.2029

Residuals Statistics

	Min	Max	Mean	Std Dev	N
*PRED	0.8314	25.0017	12.3294	5.4088	211
*RESID	-12.5457	8.2075	0.0000	1.8539	211
*ZPRED	-2.1258	2.3429	0.0000	1.0000	211
*ZRESID	-6.7348	4.4059	0.0000	0.9952	211

Total Cases = 212

APPENDIX VIII

Regression of soil texture upon Cation Exchange Capacity.

This regression model was generated from Appendix A. Chemical and Physical Analyses, Morphological and Analytical Data for Representative Soil Profiles (Twardy and Corns, 1980). Only data from horizons with <2% organic matter were used to develop these equations, since mineral soil horizons of Gray Luvisolic soils generally contain low concentrations of soil organic matter. When soil organic matter concentration is low the CEC is associated primarily with the <2 μm particle-size fraction.

Reference

Twardy, A. G., and I. G. W. Corns. 1980. Soil survey and interpretations of the Wapiti map area, Alberta. Soil Dept., Alberta Res. Coun., Alberta Inst. of Pedology. 134 pp.

The selected model:

CEC (meq (100 g)$^{-1}$) or (cmol(+) kg^{-1}) = Clay(%)

Multiple R	0.91932
R Square	0.84514
Adjusted R Square	0.84269
Standard Error	2.07604

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	1481.87547	1481.87547
Residual	63	271.52547	4.30993

F = 343.82835 Signif F = 0.0000

---------- Variables in the Equation ----------

Variable	(Coefficient) B	(SE of Coeff.) SE B	Beta	(t-stat) T	(p-value) Sig T
CLAY	0.462503	0.024943	0.919317	18.543	0.0000
(Constant)	2.464007	0.345127		7.139	0.0000

Residuals Statistics

	Min	Max	Mean	Std Dev	N
*PRED	3.3890	25.5892	11.4935	5.8119	65
*RESID	-4.3766	7.8359	0.8096	2.6618	65

Total Cases = 65

APPENDIX IX

Soil property variables selected for regression analysis for all ecological response variables (LAI, LAI adj. BA, BA, BAI and Tree Volume).

Forest Floor

1. Thickness (cm)
2. Rate of net N mineralized ($\mu g\ cm^{-3}\ 14days^{-1}$)
3. Rate of net N mineralized ($mg\ m^{-2}\ 14days^{-1}$)
4. Percentage organic-C
5. Organic-C ($kg\ m^{-2}$)
6. Percentage N
7. Nitrogen ($kg\ m^{-2}$)
8. C/N
9. Bulk density ($g\ cm^{-3}$)
10. Field pH in water
11. Moisture content ($g\ 100g^{-1}$)between 29 and 31 July 1998
12. Soil water (cm) between 29 and 31 July 1998
13. Moisture content ($g\ 100g^{-1}$)between 12 and 15 August 1998
14. Soil water (cm) between 12 and 15 August 1998

A-horizon

1. Thickness (cm)
2. Rate of net N mineralized ($\mu g\ m^{-3}\ 14days^{-1}$) between 0 and 10 cm depth
3. Rate of net N mineralized ($mg\ m^{-2}\ 14days^{-1}$) between 0 and 10 cm depth
4. Percentage organic-C
5. 1st A-horizon Organic-C ($kg\ m^{-2}$)
6. Estimated whole A-horizon percentage organic-C ($kg\ m^{-2}$)
7. Percentage N
8. 1st A-horizon Nitrogen ($kg\ m^{-2}$)
9. Estimated whole A-horizon percentage N
10. C/N
11. Bulk density ($g\ cm^{-3}$)
12. Percent Clay
13. Percent Silt
14. Percent Sand
15. Field pH in water
16. Cation exchange capacity (cmol (+) kg^{-1})
17. Moisture content ($g\ 100g^{-1}$)between 29 and 31 July 1998
18. Soil water (cm) between 29 and 31 July 1998
19. Moisture content ($g\ 100g^{-1}$)between 7 and 13 October 1998
20. Soil water (cm) between 7 and 13 October 1998
21. Estimated field capacity ($g\ 100g^{-1}$)
22. Estimated whole A-horizon field capacity ($cm^3\ 100cm^{-3}$)
23. Estimated permanent wilting point ($g\ 100g^{-1}$)
24. Estimated whole A-horizon permanent wilting point ($cm^3\ 100cm^{-3}$)
25. Estimated available water capacity ($g\ 100g^{-1}$)
26. Estimated whole A-horizon available water capacity ($cm^3\ 100cm^{-3}$)

B-horizon

1. Thickness (cm)
2. Percentage organic-C
3. 1st B-horizon Organic-C ($kg\ m^{-2}$)
4. Estimated whole B-horizon percentage organic-C ($kg\ m^{-2}$)
5. Percentage N
6. 1st B-horizon Nitrogen ($kg\ m^{-2}$)
7. Estimated whole B-horizon percentage N
8. C/N
9. Bulk density ($g\ cm^{-3}$)
10. Percent Clay
11. Percent Silt
12. Percent Sand
13. Field pH in water
14. Cation exchange capacity (cmol (+) kg^{-1})
15. Moisture content ($g\ 100g^{-1}$)between 7 and 13 October 1998
16. Soil water (cm) between 7 and 13 October 1998
17. Estimated field capacity ($g\ 100g^{-1}$)
18. Estimated whole B-horizon field capacity ($cm^3\ 100cm^{-3}$)
19. Estimated permanent wilting point ($g\ 100g^{-1}$)
20. Estimated whole B-horizon permanent wilting point ($cm^3\ 100cm^{-3}$)
21. Estimated available water capacity ($g\ 100g^{-1}$)
22. Estimated whole A-horizon available water capacity ($cm^3\ 100cm^{-3}$

APPENDIX X

Soil-site evaluation model for Tree Volume.

The selected model:

TreeVolume (m^3 ha^{-1})= FF_pHw

Multiple R	0.70468
R Square	0.49658
Adjusted R Square	0.48219
Standard Error	87.01613

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	261410.27655	261410.27655
Residual	35	265013.22067	7571.80630

F = 34.52416 Signif F = 0.0000

---------- Variables in the Equation ----------

Variable	(Coefficient) B	(SE of Coeff.) SE B	95% Confdnce Intrvl B		Beta
FF_PHW	127.506821	21.700605	83.452251	171.561391	0.704683
(Constant)	-416.981161	125.327795	-671.410113	-162.552208	

---------- Variables in the Equation ----------

Variable	Tolerance	VIF	(t-stat) T	(p-value) Sig T
FF_PHW	1.000000	1.000	5.876	0.0000
(Constant)			-3.327	0.0021

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	105.7968	437.3145	314.5978	85.2138	37
*ZPRED	-2.4503	1.4401	0.0000	1.0000	37
*SEPRED	-157.0663	233.1315	0.0000	85.7991	37
*ZRESID	-1.8050	2.6792	0.0000	0.9860	37
*SRESID	-1.8332	2.7753	0.0038	1.0153	37
*COOK D	0.0000	0.2813	0.0310	0.0597	37
*LEVER	0.0000	0.1668	0.0270	0.0361	37

Total Cases = 39
Durbin-Watson Test = 1.82519

APPENDIX XI

Soil-site evaluation model for Basal Area.

The selected model:

BA ($m^2 ha^{-1}$) = FF_PHW

Multiple R	0.48861
R Square	0.23874
Adjusted R Square	0.21699
Standard Error	8.37256

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	769.44111	769.44111
Residual	35	2453.49132	70.09975

F = 10.97637 Signif F = 0.0022

---------- Variables in the Equation ----------

Variable	(Coefficient) B	(SE of Coeff.) SE B	95% Confidence Interval B		Beta
FF_PHW	6.917669	2.087999	2.678805	11.156533	0.488610
(Constant)	-3.041945	12.058850	-27.522712	21.438822	

---------- Variables in the Equation ----------

Variable	Tolerance	VIF	(t-stat) T	(p-value) Sig T
FF_PHW	1.000000	1.000	3.313	0.0022
(Constant)			-0.252	0.8023

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	25.3205	43.3064	36.6486	4.6231	37
*ZPRED	-2.4503	1.4401	0.0000	1.0000	37
*SEPRED	1.3764	3.6859	1.8718	0.5418	37
*RESID	-18.1629	17.7312	0.0000	8.2555	37
*ZRESID	-2.1693	2.1178	0.0000	0.9860	37
*COOK D	0.0000	0.2280	0.0321	0.0545	37
*LEVER	0.0000	0.1668	0.0270	0.0361	37

Total Cases = 39
Durbin-Watson Test = 2.13825

APPENDIX XII

Soil-site evaluation model for mean annual Basal Area Increment.

The selected model:

BAIT ($m^2\ ha^{-1}\ a^{-1}$) = A1_NMINH ($\mu g\ m^{-2}\ 14d^{-1}$) + (A1_NMINH ($\mu g\ m^{-2}\ 14d^{-1}$))^2

Multiple R	0.45593
R Square	0.20787
Adjusted R Square	0.15836
Standard Error	0.15086

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	2	0.19112	0.09556
Residual	32	0.72832	0.02276

F = 4.19865 Signif F = 0.0240

---------- Variables in the Equation ----------

Variable	(Coefficient) B	(SE of Coeff.) SE B	95% Confdnce Intrvl B		Beta
A1_NMINH	-0.001106	3.8271E-04	-0.001886	-3.26841E-04	-0.965672
A1NMINH2	2.99837E-06	1.1340E-06	6.88520E-07	5.30822E-06	0.883220
(Constant)	0.634508	0.033763	0.565734	0.703282	

---------- Variables in the Equation ----------

Variable	Tolerance	VIF	(t-stat) T	(p-value) Sig T
A1_NMINH	0.221853	4.507	-2.891	0.0068
A1NMINH2	0.221853	4.507	2.644	0.0126
(Constant)		1	8.793	0.0000

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	0.5325	0.9221	0.6040	0.0750	35
*ZPRED	-0.9542	4.2429	0.0000	1.0000	35
*SEPRED	0.0312	0.1131	0.0412	0.0162	35
*RESID	-0.3230	0.3975	0.0000	0.1464	35
*ZRESID	-2.1412	2.6348	0.0000	0.9701	35
*COOK D	0.0000	1.8566	0.0766	0.3123	35
*LEVER	0.0141	0.5336	0.0571	0.0942	35

Total Cases = 39
Durbin-Watson Test = 2.29378

APPENDIX XIII

Thesis Glossary

BA refers to **B**asal **A**rea, and it is normally considered as the area of a stem at 1.3 m above ground level (*i.e.*, breast height). "If the cross section of a tree is taken at breast height, it is called the basal area. Total basal area of all trees, or of specified classes of trees, per unit area (*e.g.*, per acre or per hectare) is a useful characteristic of a forest stand. For example, basal area is directly related to stand volume and is a good measure of stand density (Chapter 17)." (Husch *et al.*, 1982).

BAI is defined in this study as the mean annual increment of the basal area. Also see *MAI*, *PAI* and *CAI*.

Bulk density is the combined "structure, texture, and porosity of soils, together with their organic matter content" (Kimmins, 1987), and it is commonly expressed in g cm^{-3} (or Mg m^{-3}) and abbreviated Db or ρ_b according to Kalra and Maynard (1991). Bulk density is calculated as follows:

$$\rho_b = m_s/V_t \qquad \text{(Marshall } et\ al.\text{, 1996)}$$

where m_s is the mass of the solid portion, V_t is the volume of the total quantity of soil (*i.e.*, volume of the solid (V_s), liquid (V_l), and gaseous (V_g) portions).

> From the view point of soil-plant relationships, the results for a number of soil parameters are expressed on a soil volume basis (*w/v*) rather than the usual soil weight basis (*w/w*). The calculation for converting from weight basis to volume basis is as follows:
>
> *w/v results* = *w/w results* x *bulk density* (Kalra and Maynard, 1991)

CAI is the abbreviation of **C**urrent **A**nnual **I**ncrement, and is a measure of yield. For example, tree height, basal area or volume, for the previous year; *e.g.*, gross total volume for 1 year (0 to 1 a, 1 to 2 a, 2 to 3 a, *etc.*). Also see *PAI* and *MAI*.

Catena is a group of soils that are related to each other by parent material type, and form a pattern along a toposequence (Agriculture Canada Expert Committee on Soil Survey, 1987), and it may also be referred to as a Soil Association. Also see *toposequence*.

Climax forest could be considered the "end point of a successional series, the climax "organism' to which the various younger forest communities inevitably mature. This point of view is close to the monoclimax theory of F. E. Clements" (Rowe, 1961). Based on experience in the boreal forest of Manitoba, Saskatchewan, Alberta and the Northwest Territories, Rowe (1961) proposes that:

> There is no single climax forest community characteristic of upland mineral soils; rather, there are numerous types - some transitional, some relatively persistent - which are fitted ecologically to particular types of land. Short-lived ecological types (forest-land types) are characterized by intolerant species, pine, aspen, balsam poplar, and birch, while the persistent ecological types are so because there species are more tolerant and, in the case of spruce (though not the fir), longer lived.

Crop is the total harvestable material accumulated over a given period (Kimmins, 1987). For example, fiber harvested from a jack pine forest after an 80 year rotation.

Dominant canopy class is "usually defined as any tree with a well-formed crown that receives full light from above and at least some of the light from the sides." (MacLeod and Blyth, 1955).

Effective LAI is the leaf area index (LAI) value as measure by the Li-Cor 2000 Plant Canopy Analyzer (Gower and Norman, 1991; Chen, 1996; Hall, 1998; Li-Cor Inc., n.d.). It may be abbreviated eLAI, LAI_e, or L_e. Also see *LAI*.

ERV or **E**cological **R**esponse **V**ariable refers to a proxy variable used to estimate net primary productivity (*NPP*). For example, leaf area index (*LAI*) or mean annual basal area increment (*BAI*).

Evapotranspiration is the term used when the "principles applied to transpiration from individual trees are extended to a whole stand and then combined with a consideration of evaporation from the canopy and litter to estimate the total flux of water vapour from a forest" (Waring and Schlesinger, 1985).

Even-age stand is a group of trees that originate at nearly the same time (Husch *et al.*, 1982). In other words, the trees belong to one age-class. The trees that most commonly occur in these stands are shade intolerant, although it is possible for a shade tolerant stand to be even-aged. According to Macleod and Bylth (1955), in even-aged stands the differences in between oldest and youngest tree ages is not >20 years. Also see *Uneven-aged stand* and *Fire-origin stand*.

Fire-origin stand refers to a forest stand that was established as a result of an intense fire disturbance, and as a consequence it is typically *even-aged*. In Alberta a "large portion of the province's white spruce is located in the Mixedwood Forest Section (B18a) of the Boreal Forest Region (Rowe 1972) where the spruce-poplar is the dominant forest type ... These stands are most often of fire-origin and therefore usually even-aged." (Johnstone, 1977).

Forb Layer includes non-woody, broadleaved plants that are perennial and up to 25 cm tall (Beckingham *et al.*, 1996). Also see *Tree Layer*, *Shrub Layer*, *Grass layer* and *Moss Layer*.

GE or **G**rowth **E**fficiency is the ratio of stem volume growth to leaf area or leaf mass (Gilmore *et al.*, 1996). In other words, the "annual growth of stem wood per unit of foliage may serve as a "growth efficiency" index" (Waring and Schlesinger, 1985).

Grass layer includes all graminoid species, such as rushes, reeds, sedges, and grasses (Beckingham *et al.*, 1996). Also see *Tree Layer*, *Shrub Layer*, *Grass layer* and *Moss Layer*.

Intolerant species are "species with little or no ability to grow in the shade of and in competition with other trees" (MacLeod and Blyth, 1955). Also see *Tolerant species*.

Labile is a description of substances that are readily transformed and available to plants (Brady, 1990; Soil Science Society of America, 1998c).

LAI is leaf area index. It is the actual projected leaf area (PLA) divided by the ground area that is covered by the PLA. It is a proxy variable for net primary production. According to Chen (1996), LAI is defined as half of the surface area per unit surface ground area.

MAI is the abbreviation for **M**ean **A**nnual **I**ncrement. MAI is a measure of the yield, *e.g.*, tree height, basal area or volume, from the beginning of the rotation to any time thereafter. An example would be gross total volume

for 10 years, 20 years, 30 years *etc.* after rotation began (0 to 10 a, 0 to 20 a, 0 to 30 a, *etc.*). Also see *CAI* and *PAI*.

Mixedwood typically refers to an uneven-aged stand with multiple tree species. In a sere, the first tree stage is typically dominated by shade-intolerant (pioneer) species, and shade-tolerant species dominate in the understory canopies. In later stages of the sere shade-tolerant species dominate all tree canopies, and form a 'continuous tree canopy'. Also see *Uneven-aged stand* and *Even-aged stand*.

- A mixedwood **site,** in the boreal forest, "is an area with climatic, topographic and edaphic conditions that favour the production of closed canopies dominated by trembling aspen or white birch in early successional stages, black spruce or white spruce in mid-successional stages and balsam fir in late successional stages" (MacDonald, 1995). It is typically well-drained, fertile land in the mid-slope position of a landscape.
- A mixedwood **stand,** in the boreal forest, "is a tree community on a boreal mixedwood site in which no single species exceeds 80% of the basal area" (MacDonald, 1995). Another definition states a mixedwood describes stands that are composed of conifer and deciduous tree species where neither represents greater than 75% of the total number of trees; with trembling aspen and white spruce as two of the most common tree species (Hostin and Titus, 1996).
- A mixedwood **forest** "is the aggregate of all boreal mixedwood sites in any distinct area", in the boreal forest region (MacDonald, 1995).

Moss Layer includes all small leaf plants without a true vascular system (Beckingham *et al.*, 1996). Also see *Tree Layer*, *Shrub Layer*, *Forb layer* and *Grass Layer*.

NPP is **N**et **P**rimary **P**roduction. NPP refers to increase in plant community mass after losses. That is, the C assimilated after losses do to consumption and respiration. (Waring and Schlesinger, 1985; Soil Science Society of America, 1998a)

PAI refers to **P**eriodic **A**nnual **I**ncrement. PAI is a measure of *yield*, *e.g.*, tree height, basal area or volume, for a given period in the rotation. An example is the gross total volume for 10 years (0 to 10 a, 10 to 20 a, 20 to 30 a, *etc.*). Also see *CAI* and *MAI*.

PAR or **P**hotosynthetically **A**ctive **R**adiation is the solar radiation in the 400 to 700 nm range (Bolstad and Gower, 1990).

Physiologically operative variables refers to soil variables that have relatively "direct and unambiguous impact on plant growth."(Klijn and Witte, 1999). For example, available water. These variables could be considered those limiting plant growth and are therefore influential on the rate of net primary production (*NPP*); Such variables are ideal as predictor variables of *ERVs*. Also see *Physiologically Conditional*.

Physiologically conditional variables refer to the interaction of soil properties that determine the physiologically operative variables, *e.g.*, soil texture and depth to ground water table interaction affecting available water (Klijn and Witte, 1999). Also see *Physiologically Operative*.

PLA or **P**rojected **L**eaf **A**rea is the amount of leaf area exposed to solar radiation. PLA is the numerator component of *LAI*.

Porosity (soil) is "the volume percentage of the total soil bulk not occupied by solid particles." (Brady, 1990)

Prediction interval is similar to a confidence interval for a parameter except the prediction interval includes an additional variance component (Ryan, 1997). It accounts for the variability around the predicted value.

Production is the total material accumulated over at given period (Kimmins, 1987). This is the ecologist term, which is comparable to *crop*.

Productivity is the average rate of accumulation of material (Kimmins, 1987). This is the ecologist term, which is comparable to *yield*.

- **Soil** productivity is the "capacity of a soil for producing a specified plant or sequence of plants under a specified system of management. Productivity emphasizes the capacity of soil to produce crops and should be expressed in terms of yields." (Soil Science Society of America, 1998a)
- **Site** productivity is the "capacity of a site to produced specific products (i.e. biomass or lumber volume) for a given vegetative configuration over a time as influenced by abiotic factors (i.e. soil, climate, physiography). Net primary production (NPP) provides the fundamental measure of site productivity. When measured at the point of leaf carrying capacity for all potential flora, NPP is a measure of potential site productivity. Rate of growth, an economic component, is occasionally used as a partial measure of site productivity." (Soil Science Society of America, 1998a)
- **forest** productivity is the "capacity of a forest to produce specific products (i.e. biomass, lumber) over time as influenced by the interaction of vegetative manipulation and abiotic factors (i.e. soil, climate, physiography)." (Soil Science Society of America, 1998a)

Property refers to some specific characteristic trait which describes or defines (ITP Nelson, 1997). In the case of soil physical properties, it is those characteristics, processes, or reactions of a soil that are caused by physical forces and can be described by, or expressed in, physical terms or equations, *e.g.*, bulk density (Brady, 1990).

Qualitative and **quantitative** are descriptive of types of data commonly used in statistics. Qualitative data are nominal and ordinal data types, and interval and ratio data types are qualitative (McClave and Dietrich II, 1991). The two types of qualitative and two types of quantitative data are described below:

- **Qualitative**
  - "Nominal data are measurements that simply classify the units of the sample (or population) into categories"(McClave and Dietrich II, 1991). Nominal data are a categorization of each sample unit; *e.g.*, the gender (male or female) of individuals in a group (sample).
  - "Ordinal data are measurements that enable the units of the sample (or population) to be ordered with respect to the variable of interest"(McClave and Dietrich II, 1991). Ordinal data are a ranking of units for a given property; *e.g.*, a supervisor's performance rating on a scale of 1 (lowest) to 10 (highest) for all of his graduate students during his career.

- **Quantitative**
  - "Interval data are measurements that enable the determination of how much more or less of the characteristics being measured is possessed by one of the sample (or population) than another" (McClave and Dietrich II, 1991). Interval data are always numerical and the values of two sample units can be subtracted to indicate differences between the sample units for the measured property; *e.g.*, the temperature (°C) at which each sample from a group of heat-resistant plastics begins to melt.
  - "Ratio data are measurements that enable the determination of how many times as much of the characteristic being measured is possessed by one unit of the sample (or population) than another" (McClave and Dietrich II, 1991). Ratio data are also always numerical and interpreted as the multiple by which units differ; an example of ratio data would be the oxygen isotope record $Oxygen^{18}/Oxygen^{16}$, or the NO_3-N/NH_4-N ratio.

Seepage is underground runoff water that seeps toward stream channels after infiltration into the ground (Soil Science Society of America, 1998b).

Shrub Layer includes woody perennials from the ground surface to 5 m (Beckingham *et al.*, 1996). Also see *Tree Layer*, *Forb Layer*, *Grass layer*, and *Moss Layer*

SI is the abbreviation for Site Index, which is a "quantitative evaluation of the productivity of a soil for forest growth under the existing or specified environment." (Brady, 1990) More commonly it refers to the maximum tree-height attained by dominant individuals in an even-age community. According to MacLeod and Blyth (1955), site index "is the finite measurement of the site quality on a particular area. It is based on the height attained" (MacLeod and Blyth, 1955).

Site quality is the "wood-producing capacity of an area" (MacLeod and Blyth, 1955).

Soil variables refer to estimates that describe some character trait or peculiarity, which includes interactions of soil properties such as soil properties on a horizon volume basis. For example, the B-horizon permanent wilting point by horizon (mm) is a soil variable which is the interacting effects of permanent wilting point (by mass), soil horizon bulk density, and soil horizon thickness.

Stand composition of a mixedwoods refers to "the mixture of tree species forming the stand. Percentage composition for a particular species means the basal area for that expressed as a percentage of the total basal area of the stand." (MacLeod and Blyth, 1955)

Stocking is the "degree to which an area is effectively occupied by living trees. Fully stocked stands theoretically contain as many trees per acre as can fully utilize the growing space available." (MacLeod and Blyth, 1955). More generally, stocking can be considered the maximum density of tree stems per unit area that can be supported by the site plant-growth resources; *e.g.*, light, water, nutrient availability.

Stoke's Law is the principle behind the sedimentation method of particle-size analysis (Craig, 1983). Stoke's Law relates radius and terminal velocity (Marshall *et al.*, 1996).

> Settling velocity is related to the radius r, of a spherical particle in the following way. The force acting downward on each particle due to its weight in water is $^4/_3\pi r^3(\rho_s - \rho_w)g$, where ρ_s is the density of the particle, ρ_w is the density of water, and g is the acceleration due to gravity. Because of the viscous resistance of the water, this is opposed by a force which Stokes found in 1845 to be given by $6\pi\eta rv$, where η us the viscosity of water and v is the velocity of fall. This resisting force is zero when $v = 0$ at $t = 0$ and it increases with increasing v until it is equal to the downward force. The particle has then reached a constant terminal velocity. On equating these two forces we obtain Stoke's Law relating radius and terminal velocity,
>
> $$v = 2(\rho_s - \rho_w)gr^2/9\eta \qquad \text{(Marshall } et\ al.\text{, 1996)}$$

Tolerant species are "species possessing the ability to grow in the shade of and in competition with other trees (MacLeod and Blyth, 1955). Also see *Intolerant species*.

Toposequence is a consecutive series of topographic (slope) positions. "A sequence of related soils that differ, one from another, primarily because of topography as a soil forming factor" (Soil Science Society of America, 1998a)

Tree Layer includes canopies greater than 5 m tall (Beckingham *et al.*, 1996). Also see *Shrub Layer*, *Forb Layer*, *Grass layer*, and *Moss Layer*

Tree volume is typically the above ground total volume of a tree, and is a measure of accumulated harvestable material, or crop, and can therefore provide an estimate of yield.

Uneven-age stand is a group of trees where individuals originate continuously. In other words the trees belong to a complete range of age-classes. Only shade tolerant trees occur in the understory of these stands, while the forest canopy (*i.e.*, overstory) may be composed of are shade intolerant and/or tolerant species. The typical frequency – diameter class distribution in an uneven-age stand is irregular, but becomes inverse J-shaped over larger areas such as an uneven-aged forest (Husch *et al.*, 1982).

Variable is a symbol representing a quantity with no fixed value (ITP Nelson, 1997). Similarly, McClave and Dietrich II (1991) define a variable as "a characteristic or property of an individual population unit."

VIF is the **V**ariance **I**nflation **F**actor and it is a test for multicollinearity, a word used to describe the near exact relationship between two or more variables (Ryan, 1997). The VIF is important because the variance of the estimate of β is a function of multicollinearity; independent regression parameters that are highly correlated may inflate the variances of the estimated β's so that the width of the confidence intervals may render one or more useless. "Multicollinearity is declared to exist whenever any VIF value is at least equal to 10" (Ryan, 1997).

Yield is the average rate of accumulation of harvestable material (Kimmins, 1987). For example, *crop* divided by the period of rotation.

Literature cited

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. Res. Br. Agric. Canada, Minister of Supply and Services Canada, Ottawa. Publ. No. 1646. 164 pp.

Beckingham, J. D., I. G. W. Corns, and J. H. Archibald. 1996. Field guide to ecosites of west-central Alberta. Nat. Resour. Can., Can. For. Serv., Northwest Reg., North. For. Cent., Edmonton. Special Rept. 9.

Bolstad, P. V., and S. T. Gower. 1990. Estimation of leaf area index in fourteen southern Wisconsin forest stands using a portable radiometer. Tree Physio. **7**: 115-124.

Brady, N. C. 1990. The nature and properties of soils. 10th. Collier Macmillian Pub., London. 621 pp.

Chen, J. M. 1996. Optically-based methods for measuring seasonal variation of leaf area index in boreal conifer stands. Agric. For. Meteorol. **80**: 135 - 163.

Craig, R. F. 1983. Soil mechanics. 3rd. Van Nostrand Reinhold (UK) Co. Ltd., Birkshire. 419 pp.

Gilmore, D. W., R. S. Seymour, and D. A. Maguire. 1996. Foliage - sapwood area relationships for *Abies balsamea* in central Maine, U. S. A. Can. J. For. Res. **26**: 2071 - 2079.

Gower, S., and J. M. Norman. 1991. Rapid estimation of leaf area index in conifer and broad-leaf plantations. Ecology **72**: 1896 - 1900.

Hall, R. J. 1998. Special lecture - leaf area index ver. 1.1. Nat. Resour. Can., Can. For. Serv., North. For. Cent. Lecture, August 1998.

Hostin, P. J., and S. J. Titus. 1996. Indirect site productivity models for white spruce in Alberta's boreal mixedwood forest. For. Chron. **72**: 73 -79.

Husch, B., C. I. Miller, and T. W. Beers. 1982. Forest mensuration. 3rd. John Wiley & Sons, New York. 402 pp.

ITP Nelson. 1997. ITP Nelson Canadian dictionary of the english language. ITP Nelson, Scarborough. 1694 pp.

Johnstone, W. D. 1977. Interim equations and tables for the yield of fully stocked spruce-poplar stands in the mixedwood forest section of Alberta. North. For. Res. Centre., Can. For. Serv., Fish. and Environ Can., Edmonton. Info. Rept. No. NOR-X-175. 24 pp.

Kalra, Y. P., and D. G. Maynard. 1991. Methods manual for forest soils and plant analysis. For. Can., Northwest Reg., North. For. Cent., Edmonton. Info. Rept. No. NOR-X-319. 116 pp.

Kimmins, J. P. 1987. Forest ecology. Collier Macmillian Pub., London. 531 pp.

Klijn, F., and J. P. M. Witte. 1999. Eco-hydrology: groundwater flow and site factors in plant ecology. Hydrogeology J. **7**: 65 - 77.

Li-Cor Inc. n.d. The LAI-2000 Plant Canopy Analyzer. Li-Cor Inc., Lincoln.

MacDonald, B. G. 1995. The case for boreal mixedwood management: an Ontario perspective. For. Chron. **71**: 725 - 734.

MacLeod, W. K., and A. W. Blyth. 1955. Yield of even-aged fully stocked spruce-poplar stands in northern Alberta. Dept. of For. Res., For. Res. Branch, Ottawa. Tech. Note No. 18. 34 pp.

Marshall, T. J., J. W. Holmes, and C. W. Rose. 1996. Soil Physics. 3rd. Cambridge University Press, Cambridge. 453 pp.

McClave, J. T., and F. H. Dietrich II. 1991. Statistics. Collier MacMillian Canada, Toronto. 928 pp.

Rowe, J. S. 1961. Critique of some vegetational concepts as applied to forests of northwestern Alberta. Can. J. Botany **39**: 1007 - 1017.

Ryan, T. P. 1997. Modern regression methods. John Wiley & Sons, Inc., Toronto. 515 pp.

Soil Science Society of America. 1998c. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 10 April, 2001. Soil Science Society of America.

Soil Science Society of America. 1998b. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 7 April, 2001. Soil Science Society of America.

Soil Science Society of America. 1998a. Glossary of soil science terms. http://www.soils.org/sssagloss/search.html. Accessed: 15 November, 2000. Soil Science Society of America.

Waring, R. H., and W. H. Schlesinger. 1985. Forest ecosystem concepts and management. Academic Press, London. 340 pp.